GRAVITATION THE DETERMINING FORCE.

E. S. Chapin

GRAVITATION
THE DETERMINING FORCE

BY

ETHAN SAMUEL CHAPIN, A. M.

CAMBRIDGE
Printed at the Riverside Press
1887

The Riverside Press, Cambridge:
Electrotyped and Printed by H. O. Houghton & Co.

As

A TOKEN OF PARENTAL LOVE,

I Dedicate these Pages

TO

MY DAUGHTER,

WHO HAS BEEN MY COMPANION AND HELPER

IN THEIR PREPARATION,

AMID THE INCESSANT CARES OF A

DISTRACTING BUSINESS.

NOTE.

For assistance in the preparation of this revised edition, reading of proofs, and the general supervision of the work of publication, I am indebted to the Rev. M. C. Stebbins, A. M., formerly of this city, and now of Cornwall, Vt.

E. S. CHAPIN.

Springfield, Mass.
September, 1887.

PREFACE.

In 1864 I presented to the public a pamphlet entitled "Gravity and Heat." Three years later I published a duodecimo volume of 120 pages, entitled "Gravitation in Nature." In these publications were set forth some conclusions which I had reached, as the result of reflection and experiment prosecuted during such brief intervals as I could command in the midst of the pressing cares of business. The study had not only given me real pleasure, but had driven me to conclusions that were certainly important if true. The clearness and firmness of my convictions seemed to me a justification of their publication, although my conclusions were at variance, in many points, with the current opinions of standard authors, and of the public who followed them.

It has been to me the occasion of special satisfaction, that several of our most thorough and eminent students of physical science, as

the result of their latest research and experiment, have reached conclusions in substantial accord with mine. This is especially noticeable in regard to the following topics: The physical condition of Jupiter; The inconstancy of the Earth's rotation upon its axis as set forth by Father Secchi of Rome and quoted by Professor Newcomb; Gravitation the source of heat, etc.

This recent and authoritative confirmation of conclusions to which I was logically driven more than twenty years ago has seemed to me a sufficient reason for revising and reprinting this unpretending volume, under the title, "Gravity the Determining Force."

ETHAN SAMUEL CHAPIN.

SPRINGFIELD, *Mass.*, 1887.

CONTENTS.

CHAPTER I.

GRAVITY CAUSES INCREASE OF DENSITY, HIGHER TEMPERATURE, AND FLUIDITY OF MATTER.

CHAPTER II.

THE THEORY OF THE TIDES.

CHAPTER III.

PRECESSION, NUTATION, AND OBLIQUITY OF THE ECLIPTIC.

CHAPTER IV.

THE SECULAR ACCELERATION OF THE MOON'S MEAN MOTION.

CHAPTER V.

GRAVITATION IN THE SOLAR SYSTEM.

GRAVITATION THE DETERMINING FORCE.

CHAPTER I.

GRAVITY CAUSES INCREASE OF DENSITY, HIGHER TEMPERATURE, AND FLUIDITY OF MATTER.

I.

Variations of Density Dependent upon Variations of Gravity.

If molten matter be congealed while under pressure, the density of the congealed mass will be greater than if the congelation had taken place while the matter was free from such pressure. The greater the pressure, the greater the resulting density, until a limit is reached beyond which the density will be nearly or quite uniform. Now, as the force of terrestrial gravitation decreases as the square of the distance from the earth's center increases, it follows that its condensing power is less on the mountain heights than at the

level of the sea; and less at the equator than at distances nearer either pole. All the tests that we can apply combine to prove: *That the force of gravitation determines the density of matter.*

II.

The Expansive Tendency of Heat Resisted by Gravity.

The expansive force of heat opposes the condensing tendency of gravitation, as is seen in the expansion of matter when the temperature is raised. But the expansion of a fluid mass resulting from an increase of temperature is less in proportion as it is subjected to greater pressure. For example, if we apply heat to a vessel of water in a receiver from which a considerable portion of the air has been removed, we shall see how much more readily it yields to the expansive force, and at how much lower temperature it will be converted into steam. Hence we conclude: *That the expansive power of heat is limited by the force of gravitation and the elasticity of the matter heated.*

III.

Density and Conductivity of Matter Depend upon Position and Condition.

In the "Principia," Book II. Prop. 20, Newton maintains that any single particle of a spherical fluid mass is pressed toward its center by the force of its own gravity, but if a second particle rests upon the first, the pressure is doubled; a third particle will make the pressure treble; a fourth, quadruple, and so on.

This law of Newton respecting pressure, like the laws given in some of our text-books to explain the expansion and contraction resulting from an increase or diminution of temperature, is only applicable to matter in certain positions. Let the earth be the spherical mass to which the law is applied, and suppose the first particle to be located on the earth's surface at its mean distance from the center, as on the 45th degree of latitude; a second particle placed above this would practically double the pressure, but as we go on building up particle upon particle, it is evident that the law, in order to be accurate, must take account of the decrease of gravitation

with the increase of distance from the center. The expansion and contraction with, or without, a variation of temperature, contrary to the laws given in the tables of many of our text-books, vary with the pressure. Since the above was first written, the principle here laid down has been repeatedly demonstrated by striking practical experiments. In the "Scientific American" for January 1, 1876, under the heading, "Expansion and Contraction by Change of Temperature under great Strain," we find the following: "It is well known that metals expand or contract by the rise or descent of temperature, according to co-efficients found by careful experiments, and laid down in the books; but it appears that the amount of this effect of heat and cold can only be correctly determined beforehand in cases where the metals are under no great strain of extension or expansion. . . . This has been forcibly illustrated in the case of the great steel bridge in St. Louis, Mo., with its arches of 500 feet span. Calculations and allowances were made for expansion and contraction by heat and cold through a range of 140° Fah., and the difference to be expected in the elevation of the center arch of the upper chord, above the City Directrix, from

the hottest day of summer to the coldest day of winter, was calculated to be about 18 inches. . . . The result of almost daily observations ranging through 106° of temperature showed an actual difference in height of $8\frac{5}{16}$ inches. The difference for this range of temperature, according to the tables, should have been about 14 inches. But we observe that, in the case of the Victoria Bridge at Montreal, the expansion in summer and contraction in winter is in perfect accord with the calculation; in this bridge, however, the expansion is only longitudinal, and is not counteracted by any strain; while in the case of the St. Louis bridge the expansion has to overcome the immense strain exerted by the weight of the structure itself and the load upon the arch, . . . so that for an arch with slight elevation in the center, the strain becomes very great, and often surpasses the actual weight many times. . . .

"In the case of the Suspension Bridge at Niagara, it was found that the elevation by contraction was less than the calculation gave ground to expect; here, too, the material acts under an immense strain."

The effect of an increase or diminution of pressure upon expansion and contraction may

not be perceptible in bodies of small mass, but could be very readily detected in a body of such magnitude as that of the earth. Without attempting to determine the amount of the variation in pressure, density, expansion, or contraction due to the superposition of matter at different altitudes, I conclude : *That the density of matter, in all its forms, depends on the force of gravitation and the weight of particle on particle.* The expansive force of heat must be taken into account in this connection.

If we take a tube a few feet in length, closed at both ends, fill it with molten matter while the tube is in a horizontal position, close the aperture, and then raise one end till the tube is vertical, the molten matter will no longer fill it, because the increased pressure has increased the density of the fluid mass. If the matter contained in the tube were not heated, its density would not be sensibly affected by the change of position and slight increase of pressure. This experiment shows, *That the expansive force of heat is more readily overcome when matter is molten,* and that the density of matter depends, in a measure, on the pressure of particle on particle; for by placing the tube of molten matter in a verti-

cal position, gravitation acts less on the matter; for, as a whole, it is removed farther from the center of the earth, but the pressure and density are greater.

IV.

Conductivity Varies with Density.

When the density of matter is uniform, its conducting power is also uniform; but if we pulverize a solid body, or in any way increase or diminish the density of a body, we increase or reduce its conducting power. It is evident then, *That the conductivity of matter increases with the density.*

If we apply condensing force to a mass of liquid matter, such force affects equally every portion of the entire mass. But if the liquid mass have considerable depth, its density cannot be uniform, since the density of the lower portion would be increased by the weight of the upper.

If we apply heat to homogeneous matter of uniform density, the conducting power tends to diffuse the heat equally through the mass; if the density is not uniform the denser portion will receive the larger measure of heat, since the conductivity of the successive strata tends to convey the heat from the rarer to the denser part.

V.

Interdependence of Temperature, Density, Compressibility, and Resistance.

If we compress a cubic foot of air, or of other matter, into a smaller space than it previously occupied, it will, henceforth, be less easily compressed. The general result may therefore be thus stated: *The capacity of matter to sustain a crushing force increases with the density.* As heat, the equivalent of force, is made apparent by resistance, the temperature of matter is increased by compression, as all substances indicate. It has been said that if a mixture of ice and water be compressed the temperature of the mixture will be lowered. This may seem to be an exception to the above law, but we should remember that the formation of ice affords a partial exception to the law that cold contracts all bodies, since the greatest density is reached above the freezing point. It is evident, too, that a portion of the heat resulting from compression is utilized in melting the ice.

Solid substances are more easily compressed when their temperature has been raised. *The*

compressibility of congealed matter, therefore, increases with the temperature.

VI.

Contraction Affected by Pressure.

Fused matter, as a rule, under ordinary atmospheric pressure contracts one eighth of an inch per foot in congealing. If the pressure is lessened before and during the process of congelation, the resultant density will be diminished, but the amount of contraction will be increased. But if the pressure be augmented before and during the process of congelation, the resultant contraction will be less than one eighth of an inch per foot, the expansive force of heat having yielded to the pressure before congelation took place. Hence we deduce the proposition: *The amount of contraction in matter, consequent upon refrigeration, depends, in a measure, upon its density.*

VII.

Bearing of the Preceding Laws upon the Condition of the Earth.

By the application of the preceding laws we are led to the conclusion that as we go

down toward the center of the earth we must reach a level where matter ceases to contract by pressure, or to expand by heat. Compression increases the density of matter, but as the ultimate molecules are supposed to be incompressible, the distance between them must decrease, until the expansive force of heat is overcome, and the molecules are forced into contact by the superincumbent mass, causing what may be termed perfectly condensed matter; and as heat is the equivalent of the intense force resisted, this matter must be intensely hot. Some scientists maintain that no amount of pressure could bring the ultimate molecules into actual contact. Were this to be conceded, our conclusion would not be affected, since under the condition supposed all known forces tending to keep the molecules asunder have given way to pressure.

VIII.

Sustaining Strength of the Crust of the Earth.

Many experiments have been tried to determine the sustaining strength of the various rocks of which the crust of the earth is composed; but experiments have not been suffi-

ciently extended upon matter varying in density and temperature, like the earth's crust, to furnish data for a definite estimate of the height to which a column of such matter could be built up before its base would be crushed. The height of the column would vary with its position on the earth's surface; for the weight of matter increases as we approach the poles, and decreases as we go toward the equator, or ascend a mountain. If we suppose the column to have been congealed from a molten state, its height would vary with the locality, since its density would depend, in a measure, upon the varying force of gravitation at these different places. If the column were cast in a vertical position in the earth, it would increase in density toward the center of the earth: the increase in density would add to its sustaining strength; but as there is more or less heat in the surface stratum, the temperature must be increasing with the density as we descend, and the sustaining strength would decrease as the temperature became very high.

IX.

Thickness of the Earth's Crust only Approximately Determined.

Further experiments may be necessary to determine, or approximate very nearly, the distance below the surface of the earth where a stratum would be crushed by the superincumbent mass. This stratum, at whatever depth it is located, is the boundary between the rigid crust and the fluid interior of the earth. Since the density, conducting power, and temperature increase as we descend in the earth, and the sustaining strength decreases as the temperature rises, it is probable that this boundary between the solid crust and the fluid interior is comparatively near the surface. It has been shown that matter increases in density as the pressure to which it is subjected increases; but this increase of density may not continue to any very great depth, for, if it did, the earth would be much heavier than it is estimated to be. We may suppose the earth's crust to be made up of an infinite number of columns all pointing toward the earth's center; the variation in the length of these columns would represent the

thickness of the crust in their several localities.

The combined surface of the exterior bases of these columns would make up the surface of the earth, while the combined surface of their bases toward the earth's center would make up the boundary surface of the fluid sphere, or melted nucleus. That we should have the melted nucleus is evident; for when the base of the solid column is crushed, the resistance to the intense force is great, and the crushed portion must be intensely hot, even to fluidity. As each column of which the earth's crust is supposed to be made up is perfectly wedged in by the columns around it, the crushed portions of one could not escape in a lateral direction, for the surrounding matter on the same level would also be crushed, and must therefore be equally hot and equally dense. If we should attempt to lengthen the shaft by adding matter to the exterior base, the interior base would be crushed. If we should remove a portion of the superincumbent weight from the exterior base, the heat would expand a portion of the matter of the crushed interior base; the intense fluid heat, the equivalent of the crushing force, would disappear, and the matter

would be refrigerated. Hence we see that the length of the column would not be increased or diminished by overloading or lightening its exterior base.

X.

Tendency of Heat toward the Center of the Earth.

Heat being the equivalent of the force resisted tends toward the earth's center, not only by the force of compression, but this tendency is also favored by conduction, for heat inclines toward the denser strata which, if undisturbed, underlie the rarer. Both these causes favor the concentration of heat in the deeper regions of the earth. Although heat is being constantly conveyed from the central portions to the surface, by thermal springs, volcanoes, and other similar agencies; and beyond the surface by the shifting currents of the atmosphere, it is not lost, as it is being constantly conducted back toward the center of the earth by the increasing density, and the consequent greater conductivity of the strata in that direction. The prevailing direction of the currents indicates that they are tending to produce an equalization of temperature; as a general rule, therefore, they move in opposition to conduction.

That heat tends to accumulate in the central portions of the earth may be confirmed still further by observations upon a tube of molten matter, such as we noted in Section III. We found that, by changing it from the horizontal to the vertical position, the bulk of the molten mass was diminished, but its quantity of heat remains undiminished; therefore it contains more heat per cubic foot than before. We shall also note an accumulation of heat in the lower portion, caused both by the increase of density and by the consequent increase of conductivity in that direction.

Again: for an additional confirmation of the tendency of heat to concentrate in the interior portions of the earth, let us examine different strata in a vertical column of sand. We find that as we descend from stratum to stratum, there is a perceptible increase in the number of grains per cubic inch, as well as an increase of sustaining strength; we must, therefore, admit that there is a corresponding increase of force, the equivalent of heat. If we cast a molten shaft in a vertical position, the conditions being such that all portions may be refrigerated as nearly as possible at the same instant, we shall find, as we

test the shaft from the top downward, an increase of density, and of crushing force; we shall also find an increase of conducting power, and a consequent increase of heat in the same direction. Now, let us suppose that our refrigerated shaft is one of the infinite number of columns that make up the solid crust of the earth, as in Section IX. If we could apply our tests to it in this position, we should find the same continual increase of crushing force, density, conducting power, and heat, as far as we could go; and as these properties increase in matter, according to the pressure, we must infer that the same law of increase holds good for the depths that are beyond our penetration.

XI.

A Fused Nucleus.

Could we penetrate these depths we should find a melted nucleus which must be more dense than the crust, for a solid will not be supported by a fluid of less specific gravity than itself. It would sink, as ice on a lake would sink, if it should be overloaded; and if the solid crust were subject to a compressing force equal to that which acts on the melted

nucleus, it would itself be crushed, and be made fluid by the condensation. The crust rests on partially fused matter, and that on the melted nucleus, and heat is not conducted from the nucleus to the surface, since matter decreases in density and conducting power in that direction. As the crust has been disturbed, the decrease in density is not regular; but the conductivity of the strata decreases very regularly, owing to the interjection of comparatively rare matter, in veins, dikes, and fissures, at the times of the various disturbances.

XII.

Objections to the Theory of a Fused Nucleus.

The theory of a melted nucleus seems to be discarded by many scientists. The "American Encyclopædia" says: "It is controverted by Sir Charles Lyell, M. Poisson, and other eminent authorities, on these grounds. When substances, as metals, are melted, their temperature cannot be raised a single degree above the point of fusion, so long as a piece of the material remains unmelted. The same principle is exemplified in the impossibility of raising water to a higher temperature than

32 F., so long as a fragment of ice remains in it."

These objections to a melted nucleus may at first seem unanswerable, but they vanish before thoughtful investigation. When a portion of matter on the surface of the earth is melted, the melted portion is usually rarer than the remaining solid part, and if the two remain in contact, the solid portion must be melted, provided that there is sufficient heat, as heat is naturally conveyed from the rarer to the denser portion. Solids that neither expand by fusion nor contract by refrigeration, have the same density whether in the fluid or solid state, and owing to the tendency of heat to diffuse itself equally the solid and fluid parts soon come to be of equal temperature when they are brought together. If the fused portion of any substance were denser than the remaining solid portion, the latter would take a superior position when they were brought together; but the temperature of each would approach as near that of the other as does the density of inferior and superior strata of little thickness. Under such conditions, it may be said that the whole mass must be fused, or the whole be congealed, for there would be no appreciable difference of temperature be-

tween the opposite surfaces of a stratum of so little thickness; but a descent of from fifty to sixty feet gives us a difference of a degree of temperature, if we leave out of account the varying surface influences. Water, unlike solid substances in general, expands when it congeals; the line of transition between the solid and fluid is definite and sharply drawn, although the variation of the thermometer in passing from one to the other may not be perceptible. The water is denser and warmer than the particles of ice that rest upon it. Let us suppose a mass of ice composed of several horizontal strata, the lowest stratum being the densest, and each one above it rarer than the one upon which it rests; then the lowest would have the largest measure of cohesive and resisting force, the equivalent of heat; the cohesive and resisting force would grow less and less from the lowest to the uppermost stratum, and the temperature would follow the same law. Like the water, the melted nucleus is denser and hotter than the crust that rests upon it, but as the variation of temperature — unlike the case of the water and ice — is considerable, between what may be termed solid and fluid, so the distance in the earth is considerable, between perfect fluidity

and the solid crust, comprising some miles of thickening matter, until we arrive at congealed matter, or a crust twenty miles, more or less, in thickness.

XIII.

Conclusions of William Hopkins, F. R. S.

From the results of experiments upon several different kinds of rock, William Hopkins, F. R. S., of London, concluded that the density and conducting power of the inferior strata greatly exceed those of the superior, and hence inferred that the melted nucleus must be hundreds of miles from the surface. The temperature of the surface strata is variable; but if, lower down, the density and conducting power of the crust were uniform, the temperature would be uniform also. In this case, an inferior stratum at a great depth would have the same temperature as a stratum near the surface. But as the density of the different strata increases with the pressure to which they are severally subjected, and their conducting power increases with the density, the nucleus must be intensely hot.

The more rapidly the conducting power increases as we descend, the nearer the surface of the earth should we find the surface of the

fluid nucleus. In a paper read in 1860 before the Royal Institution, London, by William Hopkins, F. R. S., he gives some of the conclusions that he had reached as the result of investigations to ascertain how far the observed amount of precession might be consistent with the existence of a fluid nucleus, and among them is this: "In assuming the recognized period of precession, the shell in question, in order that it promote such a result, must be at least one fifth of the earth's radius in thickness." The reasonableness of this conclusion will be considered in a subsequent chapter.

XIV.

The Surface of the Earth Changed from Fluid to Solid by Influence of Gravity.

As the density of matter depends on the force of gravitation, matter must have existed prior to its condensation by gravitation. And as resistance increases with the increase of density, the matter of which the earth is composed must have been made hot by condensation. *There must have been a time, therefore, when the earth was in a molten condition.*

Ever since the creation, gravitation has been producing its effects on the earth, and

has by its powerful and all pervading influence increased the density of matter ; but this increase of density has been unequal in different portions of the earth in consequence of the pressure of superior upon inferior masses, hence we have as a necessary result that the central portions of the earth are the more dense. Heat, being more readily conducted by the denser matter, receded from the surface, producing gradual refrigeration, and ultimately a solid crust : the same causes that produced this crust would continue to increase its thickness until the refrigeration had reached a depth at which its effects are overcome by pressure, and heat ceases to recede. With the density and conducting power of the different strata as they are, the present thickness of the solid crust is about what we ought to expect, if we suppose it to have been in a fluid state at creation.

XV.

Apparent Exceptions to Law of Increasing Density.

A large portion of the crust became rigid while under greater pressure than it is subjected to in the position which it now occu-

pies, and dissimilar rock and strata vary more or less in density and power of transmitting heat, when formed under equal pressure. These disturbances and variations cause the thermometer to indicate different degrees of temperature in different localities at the same depth. If the rock underlying any point was formed originally near the surface, and then caused to subside by the superincumbent mass, but without sufficient weight to crush it, its density and temperature might not be greater than those of the strata a little distance above; or, if rock rests upon a stratum of gravel and bowlders, conditions that may be seen in the Alps; or, if the conducting power of the inferior stratum be less than that of the superior, we should naturally have an exception to the law that temperature increases with the depth. This may account for occasional instances that are cited to disprove the universality of the law.

XVI.

Effect of Contraction upon Condition and Dimensions of the Earth.

Conduction has caused the heat of fluidity that was originally distributed through the matter which is now the solid crust to recede

to the interior and denser portions. The refrigeration and contraction of the surface took place first, that being the least dense: the inferior strata, being refrigerated subsequently, caused a lateral pressure on the surface stratum, proportionate to the contraction of the inferior strata, or the extra surface due to the heights and depressions on the surface of the earth.

If we suppose the crust to be twenty or thirty miles, more or less, in thickness, and to have contracted in congealing as much as iron or granite would do under similar conditions, which would be about one eighth of an inch per linear foot on the surface of the earth, and much less at the depth where the crust meets the fluid nucleus, as there the expansive force of heat would be largely overcome by pressure, we should then have a medium contraction of the crust of about one sixteenth of an inch per linear foot. Hence, it appears that our globe would have been but a few thousand feet larger in diameter, when in a fluid state, than it now is. It may seem that a crust only twenty or thirty miles in thickness would be too thin and weak, but ice a foot in thickness resting upon the surface of water will sustain many tons; were it a few

rods in thickness, it would readily support large buildings.

XVII.

Elevations and Depressions, How Produced.

As the refrigeration of the inferior strata advanced, the heavier portions of the solid crust gained a mechanical advantage over the lighter. This augmented by the lateral pressure on the surface stratum caused the elevation of mountains and the depression of valleys. As the force of gravity on elevated matter decreases inversely as the square of the distance from the center of the earth, the table-lands and mountains, as they were uplifted, became self-sustaining. As the weight of portions of the crust was diminished, by their elevation, so, by the breaking up of the uniform sphericity, the weight was unequally distributed and the sustaining strength was weakened. A part of the weight of the mountains and table-lands, being thrown upon the valleys and depressed portions, caused great changes in the solid strata.

XVIII.

Superficial Changes now going on.

The superficial changes which are now taking place are comparatively trifling, — local rather than general, — and are produced mostly by the aqueous agents that are changing the position of matter, and disturbing the equilibrium of the crust. But the tendencies of nature to level the surface of the earth, through aqueous and other agencies, are counterbalanced; for the removal of matter from the surface in any locality allows as much matter to expand at the opposite base resting on the fluid nucleus, as is caused to contract in another portion of the crust over the fluid nucleus by the deposit of an additional mass upon the surface above it. When any portion of the crust is loaded beyond its sustaining strength, it is crushed by the force of gravity on the superincumbent mass, and made fluid by resistance; while an equal amount of the matter of the fused nucleus rises with those portions that are becoming lighter, above the line of fluidity. When the pressure is diminished, the melted matter expands, the heat of fluidity disappears, and

uniformity of pressure, density, and temperature is gradually restored to every portion in contact with the fluid stratum. That the matter of the fused nucleus expands before congelation takes place to form the rock strata, seems very evident; for, if the granite or rock strata had been formed at the depth of many miles, it would have been necessary for them to withstand the immense pressure of the overlying mass, and in that case would have been able to sustain an equal pressure in their elevated position; indeed, they would have had even greater power to resist pressure, because of their diminished temperature. But such is not the fact. Again, if we take any representative rock that is admitted to have belonged to the lower strata, we find that its specific gravity is only about one half the average specific gravity of the earth's entire mass. This seems conclusive evidence that the matter of the fused nucleus must expand before refrigeration takes place to form the comparatively light rock strata of the earth's crust.

XIX.

Upheavals and Depressions, How Caused.

The crust varies in thickness in different localities, as would the length of the column necessary to produce the conditions that result in the status of the fluid nucleus. The variation of the centrifugal force in different portions of the earth, affects the density and thickness of the crust only as it affects gravity. Centrifugal force counteracts the force of gravitation in a greater or less degree, according to latitude. The thickness of the crust increases as we approach the equator, since in that locality the force of gravitation is less on account of the spheroidal figure of the earth. The crust where the surface is at the average distance from the center is of medium thickness, and the more elevated portions show an increase of thickness proportionate to their elevation. When we consider, first, how much shorter is the vertical line that measures the thickness of the crust than is the circumference either of its outer or its inner surface, and, secondly, that the direction of the disturbing forces is mainly vertical, it becomes evident that we must look for up-

heavals and depressions as the result of the action of these disturbing forces, and as we can determine the localities where surface changes are most active, we can determine where the crust is most liable to undergo fracture.

If matter is removed from any locality on the surface of the earth, the melted nucleus recedes from that locality. If matter be added to any portion of the surface, the nucleus moves toward that portion. The approach of the fluid nucleus to any point is equivalent to the subsidence of that point; and the recession of the nucleus from any point is equivalent to its upheaval, when compared with the level of the sea; for while the melted nucleus conforms to the center of pressure, the level of the sea also conforms to that center. Neither the altitude of mountains, nor their number, taken as a whole, is being reduced by the leveling forces.

XX.

Causes of Fracture.

When large deposits of matter are being made in any locality, that locality is subsiding; while the district from which the matter

is being removed is rising; this double movement brings a longitudinal strain upon the rising section, and at the same time a lateral pressure upon that which is sinking. The resistance of rock strata to a crushing force far exceeds its ability to resist tension. The lateral tension to which the strata of the crust are subjected renders them liable to fracture near the summit of the portions that are being uplifted. But the portions subject to the greatest lateral strain are those that lie nearly equidistant between the line of greatest upheaval and the line of greatest depression; they are therefore most liable to such fractures as allow the melted nucleus to be forced up to the surface, and sometimes to form volcanoes. The line of fracture is usually near the level of the sea, and is generally identical with the line of faults.

XXI.

Changes in Coast Line.

When large deposits of foreign matter are being made near the coast, that portion of the continent is subsiding. If the district from which material is being removed lies contiguous to a sea or an ocean, that sea or ocean is

retiring. Thus, in one locality, the sea is encroaching on the land, and in another, the land is encroaching on the sea, as, alternately, the solid crust is being depressed to form the bed of an ocean, or raised to form a mountain summit. If we could change our field of observation from the outer to the interior surface of the crust, we should there see in one locality the strata of the solid crust, whether igneous or aqueous, being transformed by condensation from the solid to the fluid state; while in another, because the pressure had been diminished, we should see a portion of the melted nucleus expanding, its heat of fluidity disappearing, and thus, by refrigeration, new plutonic rock being formed.

This rock, formed underneath localities where the crust had been lightened, and subsequently thrown up by disturbing forces in the course of ages, by the action of leveling agencies, is laid bare on the summit of some high mountain, and in its turn furnishes material for aqueous strata; for its disintegrated particles are carried down by every mountain stream, and deposited on river and ocean beds, where, by compression, they are brought under the influence of cohesion, and solidified into stratified rock.

XXII.

Mountains, Glaciers, Moraines.

The older mountains are not always the higher, for large deposits of foreign material near their bases may have caused their gradual subsidence. The plutonic rock is, therefore, found at all levels, between the ocean and the summit of the lofty and more recently formed mountains. The position of the organic remains found in stratified rocks makes it evident that these rocks have some time formed the bed of the ocean, while the glacial furrows which they bear clearly indicate that they, as well as the plutonic rocks, have some time been above the line of perpetual frost, and have been ground down and defaced by the weight and force of moving glaciers. It has been shown that the elevated and the depressed portions of the earth are continually changing their positions. Mountains with glaciers moving down their slopes have undoubtedly existed in every latitude on the surface of the earth. Rocks found in different localities, but having a marked resemblance to each other, and which, for this reason, are said to belong to particular epochs, were doubtless formed

by similar agencies, but in very different ages of the world. The same may be said of glacial furrows, which were grooved when the rocks which bear them rested at altitudes quite different from their present. Similarity of appearance and structure in rocks is not evidence that they have equal, or any definite age, although some geologists have fixed upon a particular period of the past and styled it "*the glacial and drift epoch,*" and have sought to make a chronological catalogue of the rocks. The energy and extent of glacial and drift action are not diminished as time advances, and may never have been greater, in the aggregate, than now.

Glaciers are transporting moraines and grooving the rocks as in former days. Icebergs and flowing ice are smoothing and striating rocks; are scattering bowlders, gravel, and drift on the floor of the ocean, as they did in past ages, when the present continents formed the bed of the ocean. As the motion of ocean currents, with their fields of floating ice often touching the bed of the ocean, is from the poles toward the equator, the striæ which they are producing, as well as the bowlders and drift which they are conveying, are strewed in a northerly and southerly di-

rection. Of this, abundant evidence may be found all over the surface of North America and in other portions of the globe.

The uplifting of the crust from the level of the ocean to the line of perpetual frost, with the consequent changes in the currents of the ocean, gives to the same locality, in the course of years, a radical change of climate.

XXIII.

Location of Progressive Subsidences.

Since the earth as a whole has ceased to contract, these changes may have become less rapid; but, in many localities, the lapse of a few centuries makes them easily discernible. The subsidence may be seen near the places where large deposits of material are being made, as at the estuaries of some rivers; there trees are found in a growing posture, buried below the level of the sea; and sometimes the sinking of the land has submerged large buildings.

On those portions of a continent which are subsiding, the promontories and mountains are becoming islands; while other mountains composed of various strata are being formed on those portions which are losing matter and are

being uplifted. This uplifting of the land from the ocean bed is most apparent where extended high lands or mountain ranges are near one side of the continent, and run approximately parallel to the water line, as is the case on the western coast of South America. Other conditions being equal, these changes of level are the most rapid where the surface inequalities are most marked, as is the case in the warmer climates. Where many forces have combined to change the level of a particular locality with unusual rapidity, some implements of the aborigines have become buried to a considerable depth, causing unwarranted skepticism in the minds of a few eminent men, regarding the reliability of the Mosaic account of the age of man on the earth.

The effects of upheaval and depression are, in various ways, permanently preserved in the solid crust, by fractures, dislocation, etc. A fracture that was produced in the surface stratum at, or near, the summit of an uplift, is usually represented by a rent; a like force acting upon the hotter and more plastic strata underlying the same locality, would produce a fold. Before the faults were disturbed they were probably on a line near the level of the

ocean. If erosion and denudation were very unequal on opposite sides of the continent, they may represent a somewhat greater altitude. As volcanoes are formed on those lines where the changes of level are the most frequent, and where the crust is subjected to the greatest lateral strain, they are found more or less in belts.

XXIV.

Origin, Cause, and Location of Current Disturbances in the Earth's Crust.

My purpose does not lead me to an extended description of the geographical, or the geological features of the earth; to note minutely the variations of temperature as we descend through the crust; or to name the localities of the most frequent changes, and of the most violent disturbances. This ground has been covered with considerable care and thoroughness by writers upon physical geography, and by scientists who have made the phenomena of earthquakes and the distribution of volcanoes a special study. I propose to confine myself to the origin and cause of these conditions and disturbances, and to indicate the portion of the crust, the conditions of the elements, and the seasons of the

year, in which they are most likely to occur. As the currents of seas and oceans, with their denudating and transporting forces, are subject to more frequent fluctuations than are inland streams; islands, peninsulas, and promontories are more liable to experience upheaval and depression than are portions of the mainland. The peninsula of Italy affords a striking illustration of this.

Writers on physical geography have suggested that inland tropical seas, which, with no visible outlet, are receiving a constant influx of salt, may be filling up, since none of the salt that is brought in is carried away by the active evaporation that is constantly removing the water from the surface. But even if the tendency to the accumulation of salt were not counteracted, as Lieut. Maury suggests, in his "Physical Geography of the Sea," by the tireless industry of the numberless legions of coral insects and similar tenants of the deep; and if all the excess of salt should be deposited on the bottom of the sea, it would not follow that the capacity of the sea is being diminished: for it has been shown that any extended portions of land, sea, or ocean which are receiving large deposits of matter, whether salt, coral, or any other substance, are for the

time subsiding. To this law, however, there may be exceptions. A locality may be uplifted, though it is receiving some deposits of foreign matter, provided it be situated nearly equidistant between two localities each of which is subsiding under the weight of an excess of deposit. In such a case the upheaval would result naturally from the subsidence of the more heavily weighted district on each side. This may account for the uplifting of some of the coral islands in the central portion of the Pacific Ocean.

Here and there a limited section may be found that is being uplifted, even while it is receiving deposits; because it belongs to a district which, as a whole, is being lightened. Illustrations of this are seen in some valleys; in lake and volcanic regions. Lakes thus situated are gradually filling up, — Lake Geneva is an example. Instances of an opposite character are occasionally found; a limited section that is being lightened may be undergoing a depression of level, because it belongs to a more extended district, which, as a whole, is being overloaded and is consequently going down. Some islands, peninsulas, capes, and promontories apparently come under this case.

XXV.

Subsidence and Uplifting Reciprocal.

The subsidence of the heavier portions of the crust and the uplifting of the lighter are like the effect that would be produced on an arch constructed of slightly elastic material if the equilibrium of the arch should be disturbed by lightening one part of its span and overloading another. The weighted part would sink, causing the lighter part to rise. It is evident that there would be a tendency of the uplifted portions to remain supported in their elevated positions, since by being elevated they would lose something of their weight, and a part would be transferred to the more depressed portions of the crust. That sections of the crust are being uplifted, and that something of their weight rests on the adjacent valleys, is evident from the frequent land-slides. If this were not true, such phenomena as land-slides would be unknown, and banks of earth and gravel with perpendicular sides would be familiar sights.

Let Fig. 1 represent a mountain supported in part by its base extending below the level of the sea, and in part by the lateral pressure

of the adjacent portions below the same level. Let O represent the level of an ocean on one side, and P an extended plain on the opposite side; 1, 4, 7, 9 would represent the extended and submerged base. If the sides of this mountain, instead of being sloping, were vertical, making the upper base equal to the lower, the lower part might be crushed by the excessive weight above it.

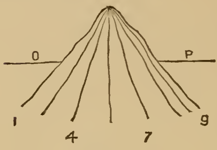

Fig. 1.

In the Yosemite Valley we have an instance in point. The complicated fracture of the rock disengaged a column with sides nearly perpendicular; its diameter seven or eight, and its circumference about twenty-five miles. In this disengaged column the weight of the superincumbent mass exceeded the sustaining strength of the base; the base was crushed; the mass sunk down hundreds of feet, and would have gone down still further had not the descent been arrested by the lateral pressure of the crust against the expanded base.

XXVI.

Uplifting and Leveling Forces Kept in Equilibrium.

As the crust is supported on the melted nucleus and the inequalities on the surface poise each other, great mountain chains must be balanced by a deep sea, or by a large extent of low level plain. The established facts of astronomy indicate that the diameter of the earth is practically invariable, therefore the elevations must, in the aggregate, equal the depressions. These movements of upheaval and subsidence counterbalance the leveling forces and maintain an equilibrium of the inequalities on the surface of the earth. Had not this been the case, it is evident from the thickness of the various strata of rock that, during the protracted geological periods which are admitted to have intervened since their creation, the inequalities on the surface of the earth would long ago have been worn down to a level.

The axis of the earth would not experience any sensible change of position by the upheaval of new mountains at different points on the earth's surface, as represented by

Newton, in his "Principia," Book I. Prop. 66, for the reason that the inequalities would balance each other. New mountains cannot be uplifted without there being somewhere equivalent new depressions. Again, if by any gradual denudation and overloading, the width of the Atlantic should be sensibly reduced, land would be upheaved in the Pacific ocean.

XXVII.

Where Leveling Forces are Most Active.

The leveling forces are not acting rapidly on the rocks that lie above the line of perpetual frost, as is evident from their jagged appearance; but a little below this line these forces are working with great energy, manifesting their effects in the heaving of the surface, the result of alternate freezing and thawing, and in the action of glaciers and torrents. The more violent action of these forces sometimes culminates in the loosening of large quantities of material, the formation of overhanging cliffs, or the frightful movements of immense avalanches of earth and rock. As these masses of rock and earth find a lower level their weight is increased; and as they are transported to a greater or less

distance, they, to a greater or less degree, derange the geographical landmarks, by their effect in lightening or overloading.

XXVIII.

Sustaining Strength of the Earth's Crust Limited.

Although the arched form of the crust gives it firmness and stability, its sustaining strength is limited, because the ability to resist a crushing force that exists in the foot of the arch and in the base of the vertical column is limited. The solidity and sustaining strength of the crust are such, with its very slight elasticity, that it resists, for a while, this gradually leveling process, before fracturing and yielding to the forces that compel it to take a new position. This resistance causes the changes of level, and the transition in the density of the matter to be more or less paroxysmal, rending the solid crust, producing shocks or earthquakes, by the fracture and concussion, at times forming new volcanoes, or reviving old ones.

XXIX.

Causes Modifying Disturbance Resulting from Fracture.

The disturbance produced when the crust is fractured varies with the nature of the soil, the face of the country, and the height at which fractures occur. The motions imparted to the crust on the line at which faults are formed are very complicated and violent, as a portion of the crust on that line is being uplifted, and a portion depressed. When the crust is fractured there is more or less of the lateral motion of opening and closing. These complicated motions and disturbances of the solid crust occasionally show their devastating power in frightful earthquakes and other similar catastrophes. When the egress from the vents is unobstructed, the disturbing effect of the concussion on the surrounding crust is somewhat lessened. Secondary causes are sometimes introduced, as when fluids pour into the fractures of the crust, and are quickly converted into steam and gases by the intense internal heat.

XXX.

Conditions under which Earthquakes are Specially Liable to Occur.

Earthquakes occur most frequently where the disturbing forces are the most intense, and act the most in unison, as when the earth is in that part of her orbit nearest the sun, and the moon is at her least distance from the earth; or when the sun, moon, and planets are in the same line with the earth, and a high tide, in consequence, rests on the area about to be depressed, as was the case in the recent earthquake in Charleston, S. C.; or when there is a sudden decrease in the pressure of the atmosphere on the continent, or on a portion of the continent and ocean. These conditions are greatly modified by the instability of the earth's axis; a topic to be considered in a subsequent chapter. The fall of the mercury in the barometer one inch would indicate a diminution of atmospheric pressure equal to the removal of a little more than one foot of water. So far as this should be over the continent, its full force would be felt in the change of surface pressure; but if it were over the ocean, the remoter waters would tend to flow in, on account of the greater pressure to which

they would be subjected, and thus the weight would be kept nearly uniform on those portions that were being depressed.

There are atmospheric tides also, corresponding with the tides of the ocean. When these tides are at their maximum at a given locality on the ocean, other circumstances being favorable, the ebb of the atmospheric tide causes the barometer to be at its minimum on the adjoining continent.

As the sun passes the equator twice every year, and the spring tides are the highest when the sun is in that vicinity, earthquakes are frequent when the sun is near the equinox.

As the land surface is more largely situated in the northern hemisphere, and as this has the least amount of snow and ice resting upon it when the sun is at his greatest northern declination; and as the disturbances have been accumulating during the year, and the vertex of the tidal wave tends to follow the sun's course in his journey to and fro across the equator, earthquakes are liable to occur when the sun approaches the northern summer solstice.

XXXI.

Varying Distances, Centrifugal and Centripetal Forces.

Irrespective of the conditions which control the expansive force of heat, a permanent increase or decrease of gravitation would cause a corresponding increase or decrease in the density of matter. When the distance between the sun and any of the planets is diminished, the centripetal and centrifugal forces acting upon these planets are augmented. As these forces act upon matter in opposition to each other, their tendency is to increase or reduce the density of the bodies upon which they act, in the ratio of the increase or reduction of these forces.

As a result of the great eccentricity of the orbits of comets, and the extreme tenuity of their substance, there is a sensible reduction in some of their disks, as they approach the sun ; another result may be that some of them by compression become self-luminous. As the distances between the sun, moon, and earth are continually changing ; and as the matter of the earth is alternately approaching, and receding from, the sun and moon, by the earth's motion on its axis and in its orbit,

the density of the earth is slightly affected by these varying influences. These disturbing forces cause sensible continuous motion of the melted matter in volcanic vents.

XXXII.

Volcanic Vents.

As the artisan is not able to braze up the last aperture in the thin shell of a hollow metallic globe a few inches in diameter, on account of the continually varying pressure on the inner and outer surfaces; so nature fails to refrigerate the melted matter in vents, and thus close up the last apertures in the crust, on account of the constant movement of the molten matter in the vents, caused by the ever-varying pressure upon its inner and outer surfaces. For this reason we must expect that volcanoes will continue. If the fluid nucleus could remain in a state of rest, the uniform pressure of the solid crust acting upon it would force it up through every vent and fissure, to a height nearly equal to that of the fluid surface before any refrigeration and contraction took place. This conclusion is confirmed by results that may be seen in many localities on the surface of the earth. Owing to the continual motion of the melted

matter, by inertia it may be carried still higher and form cones above the original level. As the melted nucleus conforms to the center of pressure, and the sea maintains a level to that center, the height to which the fluid would rise above the surface of the earth should be calculated from the level of the sea, volcanoes being more likely to overflow at the sea-level and less likely on the higher points where the crust is thicker. The crust varies in thickness, owing to the variation in density and force of gravity, and to the unequal sustaining strength of the spherical form of the crust in different districts and at different elevations. These inequalities and changes in the density of matter, and the varying egress of the fluid through the vents, giving different degrees of momentum, cause the melted matter to overflow, or to stand in the vents at different heights as regards the level of the sea.

As dissimilar inferior strata are being condensed and made fluid, at different periods, resulting from the transposition of matter on the surface, there may be a like variation in the substances ejected from the same volcanoes, or fissures, at different times. While granite may be the principal ingredient of the fused

nucleus, the various kinds of trap rock may appear as the result of the fusion of different strata.

XXXIII.

The Earth's Crust Thin, and the Interior Hot.

That the crust is relatively thin, and that the interior below this crust is in a fluid condition, is evident from the inability of such matter, at the depth of a few miles, to resist the pressure of the superincumbent mass. If we consider the steady increase in the intensity of the forces that tend to develop heat as we go from the surface toward the center, in connection with the increase in the conductivity of the strata in the same direction, we shall see that the interior must be intensely hot. Although heat tends to a uniform diffusion of itself through a horizontal stratum of uniform density, yet when the density of any portion of such a stratum becomes sufficiently reduced to admit of refrigeration, the power of conduction is nearly obliterated, so that it might remain congealed for ages, if its thawing depended upon heat received by conduction. This conclusion is sustained by the existence of permanently frozen wells, and by similar phenomena in various localities.

XXXIV.

Possible Transitions of Heat and Matter.

To illustrate the transitions through which the heat and the matter of the earth may pass, suppose that we take fifty parts of some fusible metal, and subject forty-nine parts, more or less, in a crucible to an intense heat, until it is an intensely hot fluid mass. If we should then add the remainder, it also would become fluid. So if the earth's crust could be broken up and pushed into the melted mass, the heat contained in this nucleus would restore the earth to its original fluid condition. But in process of time, the changes which it has undergone would be repeated, the heat would return to its present limits, and the whole earth would assume its present condition. To maintain that if the entire earth were thus melted, the heat could not return to its present limits, would be to maintain that what now is is impossible. If it were thus melted, the matter composing the crust would be expanded, the inequalities of the surface would be leveled, and the diameter of the sphere enlarged; but the surface of the earth would not be greatly increased, as will be apparent when we have made due allowance for

the undulations and surface wrinkles of the present formations, for the crust originally congealed when the matter was thus expanded.

XXXV.

Heat and Gravity Correlative.

In establishing the law of the conservation of gravity and heat, it becomes necessary to show that heat disappears from, or increases in, two bodies, as they approach, or recede from, each other, in the same ratio as the force of gravity affecting them increases or decreases. Gravitation is a force varying inversely as the square of the distance, and when it is resisted heat becomes its equivalent. When two bodies are attracted toward each other, the equivalent of the force of gravity is found in their accelerated motion. When that motion is resisted by any force, matter is condensed, and heat, the equivalent of the condensing force, is made sensible.

If we should remove a quantity of matter from any locality on the surface of the earth, a portion of the fluid nucleus underlying that locality would expand and heat proportionate to the force of compression removed would disappear. The solidity of the crust would

resist a transition under a particular locality, causing the expansion at the interior to extend over a larger surface, but the melted nucleus would be diminished by the removal. If the matter thus removed were attached to a balloon, and carried to the upper regions of the atmosphere, the loss of heat in the portion of the fluid nucleus underlying the locality from which the matter had been removed would be the same, and heat would have vanished from that locality and the elevated body would rest in an atmosphere less dense than that from which it had been taken. As the conductivity of a homogeneous stratum of uniform density favors the diffusion of a uniform temperature in a horizontal direction, the temperature of the elevated mass would be reduced to that of the medium in which it rests, and the frosts of perpetual winter might abide upon it. But if the elevated mass had a rigid texture that would prevent its expansion in an equal ratio with the loss of gravity, then force, the equivalent of heat, would not vanish in the same ratio. This will be apparent if we imagine the mass to be carried up beyond the influence of the earth. In this case, while gravity has diminished as the square of the distance has increased, the stored heat

of the mass has not vanished in the same ratio, for the tendency to expand has been resisted. We see then that by elevating a body, and thereby causing gravity to decrease, we do not remove the force of cohesion.

XXXVI.

Relation of Gravity to Cohesion.

As matter must have existed before gravity condensed and gave it form, the action of gravity must have been antecedent to that of cohesion. As the effects of gravity were felt before cohesion began to act, so gravity must cease to act before cohesion will give way. As cohesion originally fixed its firm grasp on the particles of solid matter as the result of refrigeration when the matter was subject to the condensing effect of gravity, heat must be restored to matter that it may expand after the condensing power of gravity shall have been removed. If to the body elevated beyond the influence of gravity, we should restore the heat that belonged to it before refrigeration, the body would be fused, cohesive force, the equivalent of heat, would vanish, and, as a consequence, the body would undergo a corresponding expansion. *The*

more rare the same substance, the greater is its capacity for force, the equivalent of heat, per pound.

XXXVII.

Effect of the Removal of Gravity.

As matter existed prior to its condensation by gravity, it might continue to exist should gravitation be removed. Gravity has been constantly producing its effects on the earth since the creative act; and, as we are led to believe by Holy Writ [1] that the force of gravitation has been suspended from a limited amount of matter, let us, for a moment, consider what the effect would be if all the matter composing the earth should be miraculously set free from the influence of gravitation. If it should be gradually set free,[2] the melted nucleus would expand, breaking the crust into fragments, and as these fragments would retain the greater density given them by pressure, they would sink, and as heat would tend toward the denser matter, they would

[1] Ex. xiv. 22; 2 Kings vi. 6; Matt. xiv. 26–29; and similar passages.

[2] If the release should be rapid, fragments of solid matter corresponding to that of meteors might be hurled into surrounding space.

necessarily be melted. Under such conditions, the prophecy in regard to the final consummation of all things would be literally fulfilled. The heat that withdrew from the crust, when under the condensing power of gravity, would be restored. The elements would "melt with fervent heat and be dissolved," and the expansion would cause the earth to "pass away with a great noise." Gravity, cohesion, and heat would vanish, and matter would be greatly rarefied. While gravitation has power to condense the rarest nebulous matter, and so produce heat, heat, in turn, has power to expand the same matter to its original nebulous condition, when released from the influence of gravitation.

XXXVIII.

Consequence of the Restoration of Gravity.

As we have not supposed any suspension of the translating forces, if after the wide separation of the particles of matter composing the earth, resulting from their release from the influence of gravitation, they should again be brought under its original power, then nature, with her present laws, would restore the present density, figure, and physical condition of

the earth, but not, perhaps, its present geographical features. Matter would be condensed and a melted mass would be produced. That portion of matter forming the surface, being the least dense, would soonest lose some of its heat, would be refrigerated and form a crust.

XXXIX.

Process of Refrigeration.

As the ruins left by some great conflagrations retain their heat for months; and as several years are often required to complete the refrigeration of matter a few feet in thickness that has been ejected from a volcano during a single eruption; what ages must have elapsed during the refrigeration of the solid crust of the earth; epochs during which the temperature was gradually decreasing on the surface. If the crust had not been disturbed, all portions would sustain force and retain heat proportionate to the density and conducting power of the strata in which they were severally formed. As it is, all portions have retained heat proportionate to their primitive density and conductivity, but modified by the normal density and conductivity of the strata to which they have been transferred. Since

the interior is subject to an immense pressure, it must be intensely hot, and this the economy of nature demands, in order to maintain motion in the fluids, and vitalize all nature. On account of the centralizing tendency of heat, if the nucleus were not intensely hot, the surface would be intensely cold.

XL.

Equalization of Temperature.

The constant transposition of the fluids of the earth tends to the equalization of heat, as is shown by the direction and temperature of the prevailing currents. The currents in the atmosphere tend to equalize its temperature; while its conductivity and capacity to sustain pressure increase with its density, thereby increasing the refrigerating forces. Hence, a dense atmosphere, on a clear evening, facilitates the deposit of dew, or the production of frost.

XLI.

Direction and Form of Inequalities, How Determined.

In consequence of the centrifugal force and the spheroidal figure of the earth, the ten-

dency originally must have been to form the inequalities on the earth's surface nearly parallel with the equator. But the unequal temperature, and the equalizing tendencies of the air and the water on different portions of the earth, cause a constant transferrence of the fluids between the poles and the equator, maintaining a constant series of currents at right angles to the equator, and by means of them wearing away the intervening barriers, giving outline and form to the continents, and tending to determine the direction of mountain chains.

XLII.

Ocean Currents Modified by Earth's Motion.

Every thing in the universe is in motion, and all matter moves in curves. The equatorial waters are being carried forward, by the rotation of the earth on its axis, about 1,040 miles per hour, while the polar waters are nearly destitute of a progressive motion. It is, therefore, evident that the equatorial currents flowing north or south would tend to the eastward of a meridian line, and that the polar waters flowing toward the equator would tend toward the westward of such a line. By

a composition of forces, the currents in seas and oceans are made to move more or less in curves as is represented in Fig. 2. Let Q R represent the plane of the equator, P the north pole, and P A the polar current flowing south to A, and W N the equatorial current flowing north. If we could now introduce a central gravitating force by drawing the water off through an opening at C, the water would have a spiral motion as represented by N O and A B. The tendency to a rotary motion as the resultant of unequal translating velocities, when taken in connection with a central motion, may be seen when quiescent water is drawn off from a bathing tub. Observation will show that, in the northern hemisphere, there is a tendency to a left hand rotary movement, and in the southern, to a reverse movement. Hence, by so simple a phenomenon as the behavior of running water in our houses, we can discover evidence of the earth's rotation on its axis, and also whether the locality of observation is north or south of the equator. Currents in the ocean become very

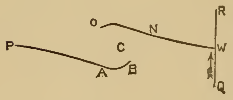

Fig. 2.

complicated in consequence of a diversity of causes of which we may name the following: 1st, Variations of temperature due to difference in locality, depth of water, and nearness to the coast line; 2d, The friction and momentum of opposing currents, as when the Gulf Stream encounters the waters flowing out from Davis Straits; 3d, The changing currents of wind; 4th, The tendency of gravitation to maintain a perfect sphere while the centrifugal force and the instability of the earth's axis are tending to pile up the water over the equator to the height of about thirteen miles.

XLIII.

Inequality of Temperature a Cause of Springs.

The unequal temperature and density of water in the earth causes springs. If we apply heat to the lower stratum of a column of water, the equalizing tendency is made visible by two currents, — the warm current ascending, and the cold current descending. Thus we see how the internal heat produces motion, and causes springs. We may also infer that artesian wells would overflow at, or above, the surface of the earth, if it were a

perfect sphere, since it would stand higher in the ascending column. The variation in the height of two columns of water that balance each other depends upon their length, and on the inequality of their temperature, since this determines their relative specific gravities. A variation in temperature may occasion a variation in height to the extent of one foot in twenty-three, or over four feet in one hundred.

CHAPTER II.

THE THEORY OF THE TIDES.

XLIV.

Influence of Sun and Moon upon the Tides, as Presented by Different Writers.

The cause of tides has long been a controverted subject. The ancients very naturally attributed the causative agency to the moon, since the position and altitude of the tides maintain nearly a constant relation to that satellite. After the law of gravitation was finally established by Sir Isaac Newton, he sought to prove in the "Principia," Book III. Props. 36 and 37, that the gravitating influence of the sun and moon on the waters of the ocean would elongate the fluid belt that encircles the earth sufficiently to produce the ebb and flow of the tides; but he calculates the density of the moon to be more than double its true density. Mathematicians of later date have decided that the "lifting power of the moon would not raise the water, or produce a tide of more than .07 of an

inch, were the ocean 10,000 fathoms deep; and that the disturbing energy of the tangential force, at its maximum, is only three fourths of the maximum lifting force."

In their explanations of the tides, the writers of our text-books on Physical Geography and Astronomy present diagrams and make statements to show that there would be a high tide formed under the disturbing body, even if the earth did not rotate on its axis. Sir John F. W. Herschel says, "were the earth indeed absolutely fixed, held in its place by an external force, and the water left free to move, no doubt the effect of the disturbing power would be to produce a single accumulation, vertically under the disturbing body."

XLV.

Causes Assigned Inadequate to Produce the Effect.

The tangential and lifting force of the moon is so inadequate to produce the tidal wave that it would not have been noticed if there had been no rotation of the earth upon its axis. If we explain the tides in accordance with the hypotheses advanced in our text-books, we do not find that relation of cause

and effect that should exist when we compare the effect produced by the moon with the corresponding effects produced by other forces of nature.

The variation of an inch in the mercurial column of the barometer is equal to the variation of $13\frac{1}{2}$ inches in a similar column of water. As the range of variation in the height of the mercurial column is between two and three inches, and this variation is due to changes in the density of the atmosphere, these changes should raise a tide in particular localities about forty times as high as the direct lifting force of the moon could do. If the comparatively feeble tangential force of the moon has any sensible effect in piling up the waters of the ocean, what vastly greater effects should we expect from the wind when it sweeps over the surface of the ocean toward the coast, at the rate of one hundred miles an hour, with sufficient force to prostrate the sturdy oak, and lay low extensive forests. The action of the wind, it is true, is confined more particularly to the surface, but the rapidity with which it forms and reverses the currents of the ocean indicates that it would drive in the waters of the ocean much faster than they could possibly return by an under-

current, on account of the large amount of friction the returning inferior current must encounter on its entire surface. The lateral force of the wind should overcome the resistance as effectually as the gravitating influence of the moon does.

XLVI.

Relative Force of Different Elements.

The variation in the pressure of the atmosphere over a specified locality should cause, at times, an elevation or depression in the waters of the ocean of nearly three feet. The disturbing effect of these elements should, therefore, if the adopted theories were correct, not only have their accredited effect on the oscillations of the ocean, but when they act in unison in favorable localities, they should exceed the effects of the sun and moon in causing the ebb and flow of the waters, and their results should be as much more marked as their measurable forces are more potent than are those of the sun and moon. That the causes of the tides are not satisfactorily explained, at least to some minds, is frankly admitted by many who adopt the present popular explanations.

Herschel says, "Many persons find a strange difficulty in conceiving the manner in which they are produced. That the sun or moon should by its attraction heap up the waters of the ocean under it, seems to them very natural. That it should, at the same time, heap them up on the opposite side seems, on the contrary, palpably absurd."

It is said that the tides are principally caused by the unequal attraction of the moon on the earth, and on the waters on its opposite sides. But the moon is only about one eightieth the mass of the earth, and attracts the waters on the earth nearly 3,600 times less powerfully than the same amount of matter in the earth attracts it, since it is nearly 240,000 miles distant. The moon, then, with its comparatively feeble force of gravitation is said to draw up the waters of the ocean nearly under it, ten feet more or less in height, while it draws the whole mass of the earth away from the water on the opposite side five feet, causing a tidal wave of equal height with the other by the lagging of the water. Yet the moon attracts the water on the side of the earth remote from itself with nearly as much force as it does that on the nearer side, since only a small

fraction of its attractive force is lost by passing through the earth. According to this hypothesis, the attraction of the moon, acting in unison with terrestrial gravitation, is not powerful enough to hold the water down to its normal level on the remoter side, while, acting in opposition to terrestrial gravitation, the moon raises a tidal wave five feet high on the nearer side of the earth. At a point on the side of the earth remote from the moon, where a high tide culminates, the water of the ocean is drawn by terrestrial gravitation toward the center of the earth, with a velocity sixty times as great as that with which the moon is drawn toward the earth; and this latter velocity is about eighty times that with which the earth is drawn toward the moon. What, then, is to prevent the water on the remote side of the earth from being attracted toward the earth's center by gravitation as fast as the earth is falling toward the moon? In the theory of the tides adopted by Herschel and others, in accounting for the high tide on the remoter side of the earth, it would seem that the force of terrestrial gravitation is ignored, while according to Newton, "Principia," p. 452, "the moon's force to move the sea is to the force of

gravity as 1 to 2,871,400. It is evident that this force is far less than appears sensibly in statical or hydrostatical experiments, or even in those of pendulums. It is in tides only that this force shows itself by any sensible effect." We must take into account the fact that Newton considered the density of the moon compared with the density of the earth as 11 to 9, while the later tables give the density of the moon 0.5657, that of the earth being 1.

XLVII.

Influence of the Earth's Rotation.

In proof that "the waters are raised by the difference of the moon's attraction on the superficial waters on both sides, and on the central mass," Herschel says: "In the theory of the moon, the difference of the sun's attraction on the moon, and on the earth, gives rise to a relative tendency in the moon to recede from the earth, in conjunction and in opposition, and to approach it in quadratures." The planets are poised between the centripetal and contrifugal forces, and any slight disturbing force enters into composition with them, and soon causes a sensible perturbation. But the water on the opposite sides of the

earth's surface is subject to conditions quite different from those that determine the mutual relations of two independent bodies in space. In the former case their behavior is really determined by the overwhelmingly predominant force of terrestrial gravitation drawing them to a common center.

The unequal attraction of the sun and moon on the opposite sides of the earth may tend to elongate the belt of water encircling it; but this unequal attraction is so slight a disturbing influence, when compared with other disturbing forces introduced by the rotation of the earth on its axis, that acting alone it might never have been perceptible in the oscillations of the ocean. This is the more apparent, when we consider that the points at which the tides culminate are changing their positions on the equator nearly 1,040 miles per hour, and that a force vastly greater than that assigned is necessary to cause the ebb and flow of the tides. But if the laws of dynamics are duly considered, in connec-

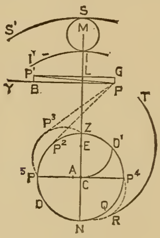

Fig. 3.

tion with the influence of the sun and moon, I believe that the phenomena of the tides will be more correctly explained.

XLVIII.

Resultant of the Several Elements.

If we place a particle of matter at P, Fig. 3, and give it an impetus toward G, its path will be rectilineal, if there is no disturbing influence to cause deviation. Let M represent the moon, and place the particle again at P; now give it an impetus that would carry it in a right line to B. Suppose that while this impetus was carrying it over the distance PB, the attraction of the moon would draw it up a distance equal to PG; then, by the composition of these forces acting together, the particle would be carried over the diagonal PP^1 of the parallelogram PGP^1B. Now let us suppose the influence of the moon to be suspended; let ZON represent the earth with the pole projected toward the observer; let the particle be placed again at P, and while it is subject to the continuous attraction of the earth, give it an impulse, as before, that would be sufficient to carry it over the line PB; it will be deflected to the earth at some

point, as P^2. Now place the particle again at P, and while it is under the attraction of both the earth and moon, give it a like impulse as before; it would now be deflected into a different path as PP^3. The particle P may represent water at the equator of the earth at P^4, with a velocity of nearly 1,040 miles per hour, and moving for twelve hours between the earth and moon, till it is brought by the rotation of the earth on its axis to the position P^5. As from P^4 to Z the water is falling toward the moon, it is gaining a momentum that would be more or less tangential after it passed the point Z, and would produce its maximum effect at some point, as P^3, as from P^3 to O it would be retarded by the action of the moon. The uplifting forces, therefore, combine to form a high tide at P^3 nearly 45° from a direct line joining the centers of the revolving and disturbing bodies.

XLIX.

Reciprocal Motions of Earth and Moon.

As the quantity of matter in the earth is about eighty times as great as that in the moon, their common center of gravity is about eighty times nearer the former than the latter,

and is therefore situated about 3,000 miles from the center of the earth, and is represented at E, Fig. 3. The earth completes a revolution around the moon on the point E in the same time that is required by the moon to complete a revolution around the earth. The mean distance between the moon and the point E is invariable, and the motion of the earth around the moon may be said to be hinged on that point. Let the plane of the line LN divide the earth into two equal sections. In the revolution of the earth on its axis, the section P^2P^5O has a motion from the moon, while the opposite section QP^4O^1 has a motion toward it.

The mean distances between the moon and the points Z and N are not affected by the motion of the earth around the moon, since Z, N, and E are on the same line; and the points Z and N have no motion either to or from the moon. The axis of rotation is then equidistant between Z and N, but as the earth is falling around the moon on the point E, the center of the earth, C, and the point R are moving respectively in the orbits CO^1 and RT. Hence R has a greater velocity toward P^4 than P^3 has toward P^5.

L.

Instability of the Earth's Axis, and its Effect.

The line in the earth that has the least motion, I shall designate as the axis of rotation. That line does not pass through the true center of the earth, but at a little remove from it as is represented at A, Fig. 3. As its angular position from a line joining the moon and the center of the earth remains invariable, the retrograde motion of the moon, when compared with the rotation of the earth on its axis, causes an instability of the earth's axis and gives an eccentric motion to the earth. The longer portion is in the direction P^4, the shorter towards P^5, and the greater centrifugal force engendered on the longer portion tends to form a high tide at R. The accumulation of the waters at P^3 and their retardation from this point to O causes an ebb tide at the latter point; and the increased centrifugal force on the longer portion of the eccentric, tending to raise the waters at R, has a tendency to cause an ebb tide at O^1. The tendency of the water to flow on from P^3 by inertia, and form a high tide on the shorter

portion of the eccentric at P^5, is counterbalanced by the decrease in the centrifugal force, which allows an equal flow in a transverse direction toward the poles.

LI.

Result were the Position of the Earth's Axis Invariable.

If the center of the earth, C, had as rapid a motion of translation in its orbit, CO^1, around the moon, as R, Fig. 3, has in its orbit, RT, the rotating velocity of R toward P^4 would be no greater than that of P^3 toward P^5. The diameter P^4P^5 would then rotate on a true and fixed center, C, and in this condition, as Herschel says, "the rotation must be performed *round an axis* or diameter of the sphere, whose *poles* or extremities, where it meets the surface, correspond always to the same points on the sphere." But this requires that the axis of a revolving body have a fixed position in space, or that every portion have an equal motion of translation, which does not admit of an orbital motion, but requires that the revolving body move in a rectilineal path. The curvilinear path of the moon, with its balanced condition, causes

the moon to have an axial rotation, giving alternate day and night to the inhabitants of the moon, if such there are.

LII.

Cause of Axial Rotation.

When all portions of a body moving continually in a given direction have not equal velocities of translation, the resultant is a motion of rotation on an axis, as well as in an orbit, as is evident in the case of the moon. In Fig. 3, let I represent the inferior point of the moon, and I^1 the orbit in which it moves when passing around the earth; let S represent the superior point and SS^1 its orbit. It is evident that the point S passes around the point I during each revolution of the moon in its orbit, and that the excess of the translating velocity of the point S over that of the point I must be such as to allow S to gain over I a distance equal to the circumference described about I as a center, with a radius equal to the line SI.

Again, the axis of rotation in a revolving body is located in the line of the least centrifugal force; its position in the moon is indicated at I, in the earth, at A. It is well

known that solar and sidereal time coincide only at certain intervals; the variation in one year is due to one revolution of the earth on its axis.

As the rotating velocity of S is greater than that of I, the centrifugal force developed in the superior or longer limb of the eccentric must exceed that developed in the inferior or shorter, for this force increases with the rotating velocity when the periodic times are equal. As a portion of the earth is falling toward the moon while the moon is falling toward the earth, the unequal centrifugal force, which is proven to exist on opposite limbs of the moon, determines the fact of the existence of unequal centrifugal force on the opposite limbs of the earth.

LIII.

Projectile from a Rifled Gun.

A condition may be conceived, when a deviation from a rectilineal path will not disturb the axis of rotation, as when a projectile is hurled from a rifled gun; or if by chance a planet should move pole foremost in its orbit, and if the centrifugal force developed by its axial rotation should be sufficient to hold its equator invariably in the same plane. This may be illustrated by Fig. 4.

Let B represent a projectile as having moved through an arc of 90° to B[1]. The sides of the ball, BC and B[1]C[1], in going from B to B[1], will have passed through equal spaces in equal times, as is represented by the dark and the dotted line, as these lines are of equal length and come in contact with the ball at corresponding points. Or, in the same Fig., A may represent a planet whose orbit is ABB[1]D. Let NS represent the axis of rotation, N the north and S the south pole ; now suppose that as it advances in its orbit from A to B[1] the north pole is foremost, and that from B[1] to A the south pole. In this case the axis of rotation will not become unstable through the influence of any disturbing force or because of any deviation from a rectilineal path, as all portions of the moving mass have equal velocities of translation, and that all rotating velocities exactly balance each other. In this example the surface of the rotating body is supposed to be uniform, and the density of opposite parts equal.

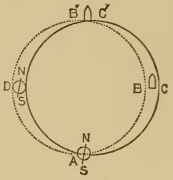

Fig. 4.

LIV.

Exceptions to Herschel's View.

When Sir John F. W. Herschel, in his work on astronomy, was presenting the subject of the precession of the equinoxes, he seemed to fear that his representation of the motion of the earth might lead some of his readers to believe that the axis of the earth is unstable, — a belief that would have been in accord with facts. He says: "The reader will take care not to confound the variation of the position of the earth's axis in space, with a mere shifting of the imaginary line about which it revolves in its interior. The whole earth participates in the motion and goes along with the axis, as if it were really a bar of iron driven through it. That such is the case will be proved by two great facts. First: That the latitudes of places on the earth, or their geographical situation with respect to the poles, have undergone no perceptible change from the earliest ages. Second: That the sea maintains its level, which could not be the case if the motion of the axis were not accompanied with a motion of the whole mass of the earth." The consideration of

the first of the above mentioned facts will be deferred to a subsequent chapter. But the ebb and flow of the tides demonstrates the fact that the sea does not maintain its level; and this result is partly due to the fact that the movement of the axis in space is not accompanied by a like movement of the whole mass of the earth. We have shown in section XLVIII. how this variation operates to produce the tides.

LV.

A Complex Problem.

When we compare the centrifugal force which should be apparent on the longer portion of the eccentric, with that which perpetually uplifts and sustains the water over the equator nearly thirteen miles in height, the tidal wave may seem much less than what we ought to expect. On the other hand, the fact is, that although the unequal attraction of the sun and moon may uplift a tidal wave to the height of a fractional part of an inch, it is entirely inadequate to sustain the burden laid upon it by the popular hypothesis, of accounting for the daily observed results. Again, in forming an estimate of the results that would be produced by the action of a

given force, it becomes necessary to take into account the obstacles with which that force must contend. This will at once make it apparent that a force vastly superior to that assigned will be required to raise a tidal wave in the ocean a few feet in height, as the point at which the tide culminates changes its place in longitude on the equator at the rate of nearly 1,040 miles per hour. As we proceed in the investigation, the great difficulty of reaching definite conclusions as to the height of the tidal wave that should result in any particular locality, from the action of any assigned force, becomes very evident. Many mathematicians and practical engineers have bestowed great care and much patient labor on the problem of the flow of water in channels with a given depth, width, and head. But suppose that they were to solve independently the problem, How long a time would be required for the accumulated waters over the equatorial regions to flow back toward the poles, and leave the earth a perfect sphere, if we suppose the rotation of the earth on its axis to be suspended without any immediate disturbance of the waters from such suspension?

When we consider the inconstant factors involved, such as the infinite variations in the

depth of the ocean, variations that cannot be reduced to law; the ever-shifting direction and magnitude of ocean currents; the equally diverse and uncertain elements of resistance resulting from the changing outline of the coast; and many other similar conditions, — should we not have reason to expect considerable diversity in the conclusions which they would reach?

The great complexity of the actual problem of accounting for the phenomena of the tides, as they now exist, becomes apparent, when we consider the transverse positions of continents; the ever-varying distances between sun, moon, and earth; the frequent changes in the direction of ocean currents and in the pressure of the atmosphere.

Again, the velocity of the water and its power to resist the disturbing forces consequent on axial rotation varies with the latitude. Then, too, currents moving in northerly and southerly directions, and tending to the formation or dispersion of a tidal wave, move more or less in curves, owing to the rotation of the earth on its axis.

LVI.

Forces Considered, Adequate to Produce the Tides.

Having thus noticed a few of the component forces which are evidently concerned in in the formation of a tidal wave, the manifest intricacy of the problem demonstrates the necessity of establishing the tables of the tides in different localities by patient and persistent observation. Without further remarks, I shall assert that the forces which have been assigned in the preceding discussion, to account for the ebb and flow of the tides, are quite adequate to produce the observed results.

The effect of the axial rotation of the earth, together with the influence of the moon, is piling up the waters of the ocean, forming a high tide nearly 45° back of the line joining the centers of the earth and moon, while the increased centrifugal force engendered on the longer portion of the eccentric, caused by the shifting of the earth's axis, is forming a high tide on the opposite side.

The sun and planets also have an influence. The effect of the sun's attraction upon the

earth's axis will be noticed more fully in another chapter.

LVII.

Location of High Tides.

As the earth has a motion of translation around the moon, on their common centre of gravity, represented at E in Fig. 3, some philosophers have attempted to account for a high tide near the nadir, by the increased centrifugal force occasioned by this motion. According to this hypothesis, N must be situated on the longer portion of the eccentric, — which is not the case, — and centrifugal force, being a secondary one, cannot be producing its effects ahead of the longer limb, but they must be back of it, as is seen in the formation of a high tide at R, nearly 45° back from the longer part of the eccentric. Therefore, if this motion should cause a high tide at the nadir, it would culminate at O, nearly 45° back of what would in that case be the longer part of the eccentric, and where the most rapid motion would be, instead of at R, nearly 45° in advance of the force which would by this hypothesis be producing it. As the mean distances between the moon and the points Z C and N are invariable, the earth

has no motion toward the moon in that direction, and the unequal attraction of the moon on the earth could not produce the tides at the nadir.

CHAPTER III.

PRECESSION, NUTATION, AND OBLIQUITY OF THE ECLIPTIC.

LVIII.

Precession. — Newton's Theory.

The motion of precession was known to the ancients, and modern works upon astronomy have made the subject familiar to the general reader. Sir Isaac Newton early encountered strong opponents to his then novel theory of gravitation. To silence them, and establish his theory beyond a reasonable doubt, he must have felt the necessity of accounting for all the observed motions of the heavenly bodies. The motion of precession, therefore, made imperative demands upon him for an explanation in harmony with his new theory.

Newton, therefore, assigned, as the cause of precession, the effect of the attraction of the sun and moon upon the excess of matter in the region of the equator of the earth. This solution, which has been adopted by modern astronomers, can be presented so as to

make it appear very plausible. When the sun and moon are away from the equinoxes, their angular position to the redundant matter in the region of the equator is such that they may seem to attract it with greater force than they do the matter in the region of the poles.

It should be noted here that the greater density of matter at the poles in a very small measure counteracts the effect of any excess of matter at the equator, and would, in the same degree, lessen the tendency of the unequal attraction, whatever there might be, on the equatorial and polar regions to produce the observed motion of the poles.

LIX.

Influence of Redundant Matter at the Earth's Equator.

If the redundant matter at the equator tends to follow the sun and moon because of any superior gravitating force inherent in it, over that of the matter at the poles, the result must be a perpetual tendency to lessen the angle of inclination between the equator and the ecliptic, until they should be brought to perfect coincidence. For when the sun and moon are north of the equator, their action on

the excess of matter at the equator would tend to draw the ring of redundant matter into the plane of the ecliptic, depressing the north pole and elevating the south ; and when they are south of the equator, their action upon the excess of matter at the equator would tend to draw the ring of redundant matter into the plane of the ecliptic, and, as before, to depress the north pole and elevate the south. When the sun and moon are together at either equinox, or are both acting in the line of the equinoxes, their action could have no tendency to change the position of the plane of the equator.

But that the poles of the earth do not have a motion tending to diminish the obliquity of the ecliptic was fully proved by Bradley ten years after Newton's death. He found that stars situated near the solstitial colure, that were nearly opposite in right ascension, appeared, at times, to undergo equal and opposite changes in declination, proving a nutation of the earth's axis, as if, applying Newton's theory, the moon, in certain parts of its orbit, repulsed, rather than attracted, the redundant matter at the equator.

LX.

Fallacy of the Newtonian Hypothesis.

In continuing the investigation respecting the Precession of the Equinoxes, the fallacy of the hypothesis under consideration becomes still more apparent. It is said that the action of the moon on the accumulated matter at the equator causes the poles of the earth to be "describing a circle or ellipse in the heavens around the pole of the ecliptic as a center," causing what is known as the Precession of the Equinoxes. According to this hypothesis, when the pole in its circuit arrives at one extremity of the ellipse the equator must be tipped in one direction, it would seem to follow that when the pole should arrive at the other extremity of the ellipse, the plane of the equator would tip in the opposite direction.

In this case, the motion of precession must be reversed during the circuit of the pole through a portion of its elliptical orbit. But observation shows a perpetual retrogression, of $50\frac{1}{4}''$ of a degree, more or less, per annum. The true cause of the retrogression of the equinoctial points from year to year, with the

variation of the obliquity of the ecliptic, and the nutation of the earth's axis, will form the subjects of inquiry in the following chapter.

LXI.

Real Causes of Precession.

In explaining the tides, it was shown in Fig. 3 that the part of the earth toward P^4 had a motion toward the moon, and that P^5 had a motion in an opposite direction, P^4 being in the longer limb of the eccentric, and P^5 in the shorter limb; and that the axis of the earth was in the position represented at A, on a line at right angles with the line L, which joins the center of the earth and the center of the moon.

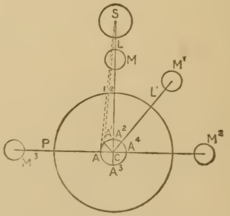

Fig. 5.

LXII.

Causes of Precession Illustrated.

Let us take a northern position in the heavens on a line with the center of the earth, C, as represented in Fig. 5, the moon, M, being in conjunction with the sun, S, the sun being at the vernal equinox. Let the line L be drawn, joining the centers of the sun, moon, and earth.

In this Fig. the axis of the earth's rotation is represented at A, and holds the same angular position to the center of the earth, C, and the line L as in Fig. 3. If we note the motion of the earth and moon as they move on in their yearly course, we shall find that when the earth has completed one revolution in its orbit, the moon has nearly completed the thirteenth revolution in its orbit, but has fallen a little back from the line L, and is at a position that may be represented by M^1. Now let L^1 be drawn, joining the centers of the earth and moon at M^1. The axis of the earth's rotation will have fallen back to the position A^1, maintaining the same angular position to the center of the earth and the line L^1 that it had to the center and the line L.

The influence of the moon on the earth, as has been shown, causes the axis of rotation to be removed from the geometrical center of the earth, giving the latter an eccentric motion. The retrograde motion of the moon, when taken in connection with the diurnal rotation of the earth, causes the earth's axis to be unstable, as it is continually dropping back to meet the moon. While the earth's center comes up, at the end of the yearly revolution, to the line from which it started, the surface lags behind, in consequence of the eccentric motion caused by the instability of the earth's axis.

LXIII.

Amount of Annual Precession Variable.

Astronomers have asserted that the amount of the annual precession of the equinoxes is not a constant quantity. In this they are doubtless correct, since it would be a necessary consequence of the fact that unequal portions of an eccentric must pass a given point in equal times. Astronomers have also asserted that the obliquity of the ecliptic is diminishing, but have failed to clearly define the cause, and to fix the limits of these variations.

I will attempt to point out the positions of the heavenly bodies in which the variations are the greatest, and those in which they are the least, but a complete verification would require patient observation extended through a long period of time.

Referring to Fig. 5, when the influence of the moon reaches the center of the earth from the position M^2, the axis of the earth is at A^2. The shorter limb of the eccentric is now passing under the sun, and when the influence of the moon reaches the earth from the position M^3, the axis is at A^3, and the longer limb of the eccentric is then passing under the sun. When the shorter limb is approaching the sun, the falling back of the surface is decreasing, and when the longer limb is coming up to the sun there is an opposite result.[1]

If the moon, represented at M^1, should, at the end of the year, come up to the position, M, from which it started at the commencement of the year, the axis A^1 would come up to the position, A, from which it started: in that case there would be no annual precession. In other words, if the moon made any number

[1] Since the issue of the former edition of this treatise Professor Newcomb and others have reached the conclusion that the time of the earth's axial rotation is not exactly constant. Professor Newcomb in *Silliman's Journal*, September, 1874.

of complete revolutions in its orbit, while the earth is making one revolution in its orbit, the point 2 on the surface of the earth would have returned to 1, the point of starting, and all portions of the earth would have had equal motions of translation, and even rotation. But as the moon fails to come up at the end of the year to its starting-point, the axis represented at A does not come up to the position A, and the dotted line 2 fails to come to the dotted line 1. The distance between these two lines, where they intersect the surface of the earth, represents the amount of the annual precession. This distance varies more or less from year to year.

LXIV.

Maximum and Minimum Eccentricity.

When the sun and planets act in conjunction with the moon, or when the distances between them and the earth are diminished, the axis of the earth deviates more from the true center, and the eccentricity is increased; so, also, when the sun and planets act in opposition to the moon, or the distances between them and the earth are increased, the displacement of the axis of rotation and the consequent eccentricity are proportionately lessened.

The annual retrogression of the equinoctial points is at the maximum, when the influence of the sun, moon, and planets have their least distance, and reaches the earth from the position M^3, as the longer limb of the eccentric is then passing under the sun. It is at the minimum, when the sun, moon, and the planets are at their greatest distance from the earth, and their influence reaches the earth in the direction M^2, as then the shorter limb of the eccentric would be passing under the sun. The instability of the earth's axis, however, depends mainly upon the disturbing influence of the sun and moon, since the independent influence of the planets must be very slight.

LXV.

Herschel on the Stability of the Earth's Axis.

In advancing the theory of the stability of the earth's axis, Herschel says: "The whole earth participates in the motion, and goes along with the axis as if it were really a bar of iron driven through it." "That such is the case," he says, "is proved by two great facts: 1st, that the latitude of places on the earth, or their geographical situations with

respect to the poles, have undergone no perceptible change from the earliest ages."[1] It should be remembered that the amount of the shifting of the axis that would be adequate to account for the motion of precession would be so small that it would be impracticable to detect it by any such test as geographical displacement.

LXVI.

Variable Direction of the Inluence of Disturbing Bodies.

Thus far in these investigations, the influence of the disturbing bodies has been considered as reaching the center of the earth through the plane of the equator. It follows, then, that the precession of the equinoxes would exist, if the sun, moon, and planets moved constantly in this plane, and that, too, whether the earth were solid or fluid; whether it had a thick or a thin solid crust; whether it was spherical or had its present figure.

If we could view the axis of the earth from the equinoctial point 1, Fig. 5, it would be situated at A, at the extremity of the dotted line 1, and perpendicular to it. In this posi-

[1] The second fact here referred to has been considered in Section XLVIII. Chap. II.

tion the poles are equidistant from the moon, and have an equal motion toward that satellite. When the influence of the moon reaches the center of the earth through either hemisphere, that hemisphere is partially in the shorter limb of the eccentric, and the opposite hemisphere is equally in the longer limb.[1]

LXVII.

Axis of Rotation not Coincident with the Geometrical Axis.

The inclination of the axis of the earth to the plane of the ecliptic, and the motion of the earth in its orbit, cause the influence of the sun and moon to reach the center of the earth through the northern or southern hemisphere, except when they act in the line of the equinoxes. When they are vertical over the summer solstice, their influence reaches the center of the earth through the northern

[1] These conditions cause the ebb and flow of the tides on the longer limb of the eccentric at the nadir, in the opposite hemisphere from the disturbing body.

The tidal forces would be rapidly decreasing in the higher latitudes, in consequence of the less rapid axial velocity, were it not that the tendency of matter to move in a given plane decreases with the velocity, and the points at which the tidal wave culminates changes its position less rapidly.

hemisphere. The south pole is then in the longer limb of the eccentric, and the north pole is in the shorter limb.

If the influence of the sun and moon were removed from the earth, its path in the heavens would become rectilineal, and its axis of rotation would coincide with its geometrical axis. With a given axial velocity, the more rapid the deviation from a right line, the the greater would be the remove of the center of the axis of rotation from the geometrical center.

LXVIII.

Theories of Nutation.

When the influence of the sun and moon reaches the center of the earth through either hemisphere, that hemisphere is in the short limb of the eccentric, and the opposite hemisphere is in the longer limb and has a more rapid motion toward the moon than the shorter. This has the effect to elevate one pole and depress the other, thus affecting the obliquity of the ecliptic.

When the disturbing influence crosses the equator, the pole that was before depressed is now elevated, and thus is produced the motion that is termed the nutation of the earth's axis. This theory of the cause of nu-

tation has the advantage over that which attributes it to the influence of the sun and moon upon the excess of matter about the equator, inasmuch as the former theory assigns a cause which tends at one time to increase and at another to diminish the obliquity of the ecliptic; while the latter theory, that of Newton, assigns a cause which tends constantly to bring the plane of the equator and the plane of the ecliptic into coincidence.

The tendency of matter on the equator to move in a given plane, in consequence of the axial rotation, combines with the motion of nutation, and the resultant of these forces is a modified circuit of the poles in space.

The sun and planets have their independent influences, and at times they act more or less in unison, causing a variation of the position of the earth's axis, and making the poles of the earth to describe irregular undulating ellipses in the heavens, around the poles of the ecliptic.

The return of the poles of the earth to given points in the heavens, and the return of the plane of the equator to a given position in relation to the plane of the ecliptic, depends upon the return of the sun, moon, and planets to a given position in the heavens, in relation to the center of the earth.

CHAPTER IV.

THE SECULAR ACCELERATION OF THE MOON'S MEAN MOTION.

LXIX.

Moon's Acceleration.

When Dr. Halley and other eminent astronomers came to compare the astronomical records of the ancient Chaldeans and Arabians with modern lunar tables, they found convincing evidence that, during the intervening centuries, the periodic time of the moon's revolution had undergone a perceptible diminution; or, in other words, that there has been a perceptible acceleration of the moon's mean motion in her orbit. How to ascertain the physical cause of this acceleration was a problem that greatly perplexed astronomers during a considerable portion of the eighteenth century.

The French Academy of Sciences at Paris, ever zealous to advance the cause of true science, offered a prize in 1770, to induce a thorough study of this problem, and to bring

about, if possible, a determination of the question whether the acceleration could be accounted for as an effect of gravitation. Euler, one of the first mathematicians of the age, received the prize, although he did not reach a solution of the problem. He says: "There is not one of the equations about which any uncertainty prevails, and now it appears to be established by indisputable evidence, that the secular inequality in the moon's mean motion cannot be produced by the force of gravitation."[1] Earnestly desiring a solution of this intricate and interesting problem, the Academy of Sciences continued to offer its stimulating prizes.

Euler extended his researches, and reaffirmed his previous conclusion; saying, at the same time, "That no doubt henceforth could exist that the inequality arose from the resistance of an ethereal fluid pervading the celestial regions." The resistance, it was said, would "lessen her centrifugal force. The earth would consequently draw the moon closer to herself, thus diminishing the magnitude of her orbit and decreasing her periodic times."

Others investigated this interesting and per-

[1] Grant's *History of Astronomy*, pp. 61–64.

plexing subject, and received the prize. But none were able to account for the acceleration by the theory of gravitation.

LXX.

Hypothesis of Laplace.

While other scientists were thus becoming skeptical upon the theory of gravitation, Laplace remained a firm and constant believer and advocate. He may, therefore, have felt that necessity was laid upon him to assign the physical cause of the discovered acceleration of the moon's orbital motion. Herschel says: "It was in this dilemma that Laplace once more stepped in to rescue astronomy from its reproach." And it seems that Laplace ended the controversy by advancing the hypothesis "that it depends on the secular variations of the eccentricity of the earth's orbit." He found that "the action of the *planets* produced nothing of the kind." He traced the disturbance directly to the sun.

LXXI.

Objections to the Hypothesis of Laplace.

But how can the sun "transmit," or, as he says, "reflect" back to the moon the action of the planets, so as to affect its periodic time, without affecting the periodic time of the earth, when the earth is a near neighbor of the moon? Then, again, the orbits of the moon and earth are both concave toward the sun; and the moon's orbit, viewed from the sun, dwindles almost to a point, since the diameter of this orbit is only about one half the diameter of the sun.

The mean distances of the moon from the earth, and of the moon and earth from the sun, depend upon their centrifugal and centripetal forces, since the forces poise each other. That these forces are constant between the sun, moon, and earth is proved by the permanent uniformity of the periodic times of the earth.

On account of the constant variation in the positions of the planets, any "transmitted" or "reflected" action from them through the sun would cause irregularity in the motions of the earth. That Laplace, then, did not assign

the true cause of the acceleration of the moon's mean motion, is proved by the fact that the force assigned does not proportionately affect the motion of the earth. If the power to produce the accleration of the moon can be traced to the sun, according to the theory of Laplace, may it not be that this power is inherent in that body, instead of being "reflected from the planets?" As the planets are poised between the centrifugal and centripetal forces, if the attraction of the earth on the moon were decreasing in any measure, the length of the moon's orbit would be increasing, and its periodic time would be increasing also, instead of diminishing, as shown by the results of comparison.

LXXII.

Is the Earth's Orbit Becoming a Circle?

The orbits of the planets are doubtless subject to perturbations consequent upon the influence of each upon the other, but this fact hardly warrants the assertion of Herschel, "that the eccentricity of the earth's orbit is, and has been, since the earliest ages, diminishing; and this diminution will continue (there is little reason to doubt), till the eccentricity is annihilated altogether, and the earth's orbit

becomes a perfect circle." "The time required for these evolutions," Herschel says, "has not been calculated." This is undoubtedly true.

LXXIII.

Moon's Acceleration not Due to Change in Orbit.

Astronomers teach that the mean distances of the planets from the sun never change, and that the periodic time of revolution for a given mean distance is always the same, whatever be the eccentricity of the orbit. Newton, moreover, maintains that if the orbits of the planets were changed to circles whose diameters were respectively equal to the transverse diameters of the ellipses, their periodic times would remain unchanged. But this change would increase the length of the orbits; therefore, if the periodic times should remain the same as before, there must be an increase of orbital velocity. It is evident, then, according to this theory, that if the earth's orbit, as some astronomers claim, is changing from an ellipse to a circle, its length is increasing; but it is impossible that the resulting increase in the length of the moon's orbit should cause the acceleration of the moon's mean motion.

As the mean distance is invariably the same and the ellipse is shorter than the circle, the orbits of the planets can never become circular orbits.

LXXIV.

Moon's Acceleration not Due to Ethereal Resistance.

"Many mathematicians of more modern days have considered the problem and have reached the conclusion that there are still slow changes in the motion of our satellite which gravitation has not yet accounted for."[1]

The secular acceleration of the moon's mean motion has been attributed to "the resistance of an ethereal fluid pervading the celestial regions." If there were any such resistance in space affecting the periodic time of the moon, the same cause must in like manner affect the periodic times of the earth and the other planets. But this theory has been at times so strongly maintained that I shall notice it more particularly in a succeeding chapter. Although there are objections to all the theories that have been advanced to explain the secular acceleration of the moon's motion, the fact

[1] Newcomb's *Popular Astronomy*, p. 99.

of the secular inequality has been demonstrated by incontestable evidence. The inquiry, then, for the true cause of this phenomenon becomes one of exceeding interest.

LXXV.

Laplace traces the cause of Lunar Acceleration to the Sun.

"Laplace, with others, studied the lunar problem with the most scrupulous care. He came to a positive conclusion that the causative influence of the lunar acceleration emanates from the sun." If he had considered the disturbing effect of the sun's attraction upon the position of the earth's axis he would probably have discovered the true physical cause.

The facts of astronomy afford many indications that the sun has a proper motion in space. According to Herschel's calculations, the sun is moving at the rate of 422,000 miles per diem. The sun, then, as well as the moon does not hold the same position at the end of the year that it had at the beginning.

LXXVI.

Influence of the Sun and Moon on the Stability of the Earth's Axis.

In our explanation of the physical causes of the tides, of the precession of the equinoxes, and the variation of the obliquity of the ecliptic, it was shown that the deviation of the earth from a right line, occasioned by the gravitating force of the sun, moon, and planets, causes the removal of the axis of rotation from the position of the geometrical axis, thus giving an eccentric motion to the earth. The disturbing effect of the moon on the position of the earth's axis, when considered by itself, tends to maintain a limb of the eccentric of uniform length, invariably turned toward itself; and to cause a limb of constantly varying length to be passing under the sun. The disturbing influence of the sun tends to produce similar results, but of less magnitude. When the sun acts in conjunction with the moon, the length of the shorter limb of the earth is diminished, and the longitude of the moon is increased. When the sun and moon act in opposition, the effect is reversed.

LXXVII.

The Sun's Motion an Element in the Problem.

If the sun maintained a fixed position in the heavens, the disturbance that we have been considering would have been compensated at the end of the year; for while the moon's motion would have been apparently accelerated, in one part of her orbit, it would have been equally retarded in another.

In the discussion of the subject of precession it was shown that if the moon should occupy the same position at the end of the year that it had at the beginning, there would be no annual precession. But the longitude of the sun and stars is increased by the disturbing effect of the moon upon the position of the earth's axis, and the motion of the moon is accelerated by the disturbing effect of the sun on the same.

The amount of acceleration of the moon's motion, that observation seems to have established, is 11″ in a century. Whether the influence of the sun and planets operating to disturb the position of the earth's axis is adequate to produce that acceleration, it may be

difficult to determine with accuracy, on account of the uncertain data respecting the proper motion of the sun in space, and the complex influences of the planets.

LXXVIII.

The Lunar Acceleration likely to Continue Indefinitely.

Herschel says: "The earth's orbit will become a perfect circle, the tables will be turned, and the process of ultimate restoration will commence, after which it will again open out into an ellipse, the eccentricity will again increase, attain a certain moderate amount, and then again decrease." According to this hypothesis, the acceleration of the moon's orbital motion will continue while the earth's orbit is conforming to a circle, but when it begins to return to the elliptical form, the moon's motion will be subject to a continual retardation.

Laplace says: "Future ages will develop these great inequalities, which are periodical like the variations of the eccentricity of the earth's orbit, upon which they depend."

On the other hand, it seems more probable, that the moon's mean motion will continue to

be accelerated, as long as the sun continues to change his place in the heavens; that no future day will witness its retardation, whatever variation there may be in the form of the earth's orbit; and that the longitude of the sun and stars will continue to increase as long as the moon accompanies us in our passage through celestial space.

CHAPTER V.

GRAVITATION IN THE SOLAR SYSTEM.

LXXIX.

Laws of Matter Uniform throughout the Solar System.

In a previous chapter we briefly considered the law of density, and indicated some of its effects on terrestrial matter. It will now be assumed that the same law is applicable to all the bodies of the solar system. There is abundant evidence that matter throughout the universe is under the control of gravitation, and is subject to similar mechanical laws. The wonderful revelations made within a few years by the aid of the spectroscope furnish striking proof that the elements that compose the earth abound in bodies remote from our system. This strengthens the probability of the universal prevalence of the laws that govern matter here.

LXXX.

Forces that Determine the Moon's Path.

In a paper read before the Academy of Sciences at Northampton, Professor Alexander said, in substance, that the center of gravity in the moon does not coincide with the geometrical center of the figure, but that it is located farther from the earth than is the geometrical center of the moon. He gave no reason for this statement. His assertion may have been based on the mathematical calculations of Professor Hansen, the German astronomer, as I believe is the custom of most astronomers. According to his estimate, the moon's geometrical center is thirty-three English miles nearer to us than is her center of gravity.

I have not seen his original calculations, but from the tenor of the following extract from the book entitled "God's Glory in the Heavens," I think that the fallacy of his hypothesis rests upon his comparison of the motion of the moon to that of a cannon ball hurled from a gun through the resisting medium of the atmosphere. "In discharging a ball from a gun, calculation can predict the trajectory it will describe. But if the ball

is not equally dense on opposite sides, it will not pursue the same path it would do if homogeneous. Given the difference of density, the curve can be laid down; and given the curve, the difference of density can be determined." The conditions are in no wise similar. The motion of the moon in celestial space is free from resistance, and depends solely on the centripetal and centrifugal forces.

LXXXI.

Unequal Density of the Superior and Inferior Limbs of the Moon, and of Comets.

It is well known that if a guinea and a feather be dropped at the same instant, and from the same height, in a vacuum, they will fall through equal spaces in equal times; but if, the other conditions being the same, they are let fall in the atmosphere they will not reach the ground at the same instant. If the feather were attached to the guinea, then the portion of the guinea most remote from the feather would reach the ground first; and so would the heavier side of a ball, when the inequality in the density of the opposite sides is considerable. It is admitted that centrif-

ugal force is excited in a revolving body, and that it increases with the velocity when the periodic times are equal. The periodic times of the superior and inferior limbs of the moon must be equal in their revolution around the earth. As the superior limb of the moon is the more distant from the earth, it must move in a correspondingly longer orbit. The velocity and centrifugal force of the superior limb must therefore be greater than the velocity and centrifugal force of the inferior limb. When a mass of matter of unequal density, under the influence of centrifugal and centripetal forces, is caused to move in an orbit around a central body, the rarer limb will move in the longer orbit, and will have the greater velocity and centrifugal force. If the earth's attractive power were increased so as to bring the moon nearer to the earth, the inequality in density of the superior and inferior limbs of the moon would be increased thereby, as the inequality in density must increase as the distance diminishes. If the present inequality in the density of the nearer and remoter limbs should be materially increased, there would be a greater tendency of the lighter and the heavier limbs to separate from each other, and thus to elongate the

figure of the moon. This tendency of the lighter limb to move in a longer orbit may account for the occasional division of a comet as it is approaching the sun. In this position the density of the limb nearer the sun would be increasing faster than the density of the remoter, hence they might separate and move on in independent orbits. If there are comets that wander from one system to another, their movements are doubtless controlled by the laws already considered. If the various systems of the universe are moving in space they may, at one time, be receding from, and, at another, approaching each other. A comet, then, moving through the remoter part of its extremely elongated orbit might come so near another system as to be brought under the control of its attractive power. If, however, there were no power of gravitation outside the solar system, no comet could ever permanently withdraw from it.

LXXXII.

Illustrative Experiments.

If we elongate a sphere of unequal density, so as to form an exaggerated representation of the figure and condition of the moon, poise

the elongated body on a pivot that reaches the center of gravity through the shorter diameter, and then cause the pivot to move rapidly in a circle whose plane is horizontal, we shall find that the longer and rarer limb of the body will move in the longer orbit. We suppose the body to be poised on the center of gravity, for the force that moves this point moves the whole body, and if all parts of the body are equally free to rotate, when rotation begins, the axis of rotation invariably seeks the center of gravity through the shorter diameter. If the motion of rotation is combined with one of translation that holds the body in position, the axis of rotation may coincide with the longer diameter, as is the case with an elongated rifle projectile. Or, again, if we support one extremity of the axis of rotation, this axis may be made to coincide with the longer diameter, as may be seen in a rapidly revolving elongated top. But whether the axis of rotation coincide with a longer or shorter diameter, it will seek the center of gravity. This may be seen in the effort of a spinning top to right itself when tipped several degrees from a vertical position. If we harness a top and place the axis of rotation in a horizontal position, or try

the same experiment with a gyroscope, the effort of the axis of rotation to find the center of gravity through the point of support will tend to balance the force of gravitation, for the movement in either case is upward. If we elevate the unsupported extremity of the axis of rotation above a horizontal position, this axis will tend still more strongly to find the center of gravity through the point of support, because the weight will be thrown more and more nearly over the point of support by the decreasing length of the lever, and the increasing power of leverage.

LXXXIII.

The Rarer Limb Moves in the Longer Orbit.

Referring again to the case of the elongated sphere. If the body should be poised on the center of the figure, instead of on the center of gravity, and then the pivot should be moved with varying velocity in an ellipse, thus representing the motion and path of the moon, the denser limb would not move in the longer orbit, but would be subject to more frequent axial rotation, caused by the unequal momentum existing in the opposite limbs.

According to the law laid down in Chapter I. the density of the inferior limb of the moon must exceed the density of the superior, because gravity acts with more force upon it; and the density of those portions that have the greatest centrifugal force is diminished, in consequence of their being uplifted to a greater distance from the center of the mass. The rarer matter on the moon, as well as on the earth, moves in the longer orbit, where the centrifugal force is the greatest. Hence the air and water, if there are any, and the lighter material are mainly on the superior limb of the moon. According to the law of density, the center of gravity in the moon must be nearer the earth than the geometrical center of the moon is, and therefore according to the laws of dynamics it could not move in the inverted position suggested by Professor Hansen; and, again, it will follow, that if the trajectory of the moon depends primarily upon its unequal density, it is not governed by gravitation.

LXXXIV.

The Balanced Condition of the Moon, and Other Satellites.

The distance between the sun and moon being far greater than the distance between the earth and moon, it is evident that the inequality of the earth's attraction on the opposite limbs of the moon must greatly exceed the inequality of the sun's attraction upon the same portions. Hence the preponderance of terrestrial gravitation on the denser limb causes the moon to be a balanced figure exposing only its loaded or denser limb to the earth.

The balanced condition of the moon explains the singular phenomenon of the uniform rotation of the satellites of the different planets on their axis with each revolution in their orbits, although the lengths of their orbits and the times of their revolution are very unequal. Laplace said: "It is well known that the satellites present always the same face toward Jupiter, as the moon does toward the earth." Herschel, when speaking of the most distant satellite of Saturn says: "It is presumed with much certainty that this

satellite revolves on its axis in the exact time of rotation about the primary, as we know to be the case with the moon, and as there is considerable ground for believing to be so with all secondaries."

LXXXV.

Conditions likely to Affect the Temperature of the Moon's Surface.

The moon is the more stable in its balanced position when it has its mean motion in its orbit, and its denser side is turned toward the earth and sun, as when the moon is in opposition to the sun. The unequal momentum in the superior and inferior limbs of the moon, resulting from their unequal orbital motion, when taken in connection with the varying angular position of the sun and its unequal gravitating influence on the opposite limbs of the moon, causes the oscillations termed librations in latitude and in longitude, as the moon is balanced toward the center of the earth, and its path departs from the plane of the ecliptic. As the moon's orbit maintains an angle with the plane of the ecliptic of about 5°, and the heavier limb of the moon is turned toward the center of the

earth, it is evident that the axis of the moon is inclined to the plane of the ecliptic, and that this must determine the lunar seasons.

Some scientists have concluded that there must be great extremes of heat and cold on the surface of the moon, because the duration of a single day and night must equal one of our months. But to determine the heating effect of the sun's rays upon the surface of one of the planets, or of the moon, we must take into account all the known conditions that modify such effect. We know that the heating power of these rays depends very much upon the density of the matter upon which they fall. Note, on the one hand, their effect upon the rare atmosphere on the summit of a lofty mountain; and, on the other hand, their effect upon the denser air of the valley. While the former may be in perpetual frost, it may look down upon the latter basking in the genial warmth of a tropical clime. The denser and the rarer matter have each their special capacities for heat, a fact that is turned to practical account in the artificial formation of ice. Because the matter of the moon is much rarer than that of the earth, the greater length of the lunar day and night would produce much less variation in

temperature than a similar cause would do under the conditions with which we are familiar.

At the annual meeting of the American Association in 1857, Professor Henry of the Smithsonian Institution, read a paper prepared by Mrs. Eunice Foote, giving the results of some interesting experiments that confirm the positions we have taken. "Mrs. Foote took two glass cylinders of the same size, containing thermometers. Into one the air was condensed, and from the other it was exhausted. When they were of the same temperature, the cylinders were placed side by side in the sun, the thermometers in the condensed air rose more than twenty degrees higher than those in the rarefied air. This effect of rarefaction must contribute to produce the feebleness of heating power in the sun's rays on the summits of lofty mountains. Secondly, the effect of the sun's rays is greater in moist than in dry air. In one cylinder the air was saturated with moisture, in the other dried with chloride of lime; both were placed in the sun, and a difference of about twelve degrees was observed. This high temperature of sunshine in moist air is frequently noticed; for instance, in the intervals between summer showers. The

isothermal lines on the earth's surface are doubtless affected by the moisture of the air giving power to the sun, as well as by the temperature of the ocean yielding the moisture. Thirdly, a high effect of the sun's rays is produced in carbonic acid gas. One receiver being filled with carbonic acid, the other with common air, the temperature of the gas in the sun was raised twenty degrees above that of the air. The receiver containing the gas became sensibly hotter than the other, and was much longer in cooling. An atmosphere of that gas would give to our earth a much higher temperature; and if there once was, as some suppose, a larger proportion of that gas in the air, an increased temperature must have accompanied it, both from the nature of the gas and the increased density of the atmosphere."[1]

LXXXVI.

Laws Determining Magnitude of Melted Nucleus.

By the application of the laws that were cited in the First Chapter, it becomes evident that the magnitude of the melted nucleus of the earth would be enlarged; the density and

[1] *Annual of Scientific Discovery*, 1857, pp. 159, 160.

conductivity of the crust would be increased; its thickness would be reduced, and the surface temperature raised, if the force of gravitation should be intensified, and *vice versa.* This law is applicable to all the bodies of the solar system, and shows that the density of a portion of the melted nucleus of all the planets must be the same, and that their surface temperature does not depend upon their distances from the sun.

LXXXVII.

Varying Density of the Planets.

The decrease in the density of the planets as the force of gravitation affecting them decreases indicates a homogeneous substance. Their density and physical condition are determined by the force of gravitation, but the ratio between their density and distance from the sun is not uniform, since the force of gravitation varies with their mass, figure, and distance of the surface from the center, because of their unequal magnitudes, surface temperature, and gravitating influence of each on the other (as the influence of the moon on the earth), as well as their distances from the sun.

If any of the bodies are so comparatively light; or if gravitation has received so little resistance that they have not been melted, their chemical forces have not been expended; they are not reduced to the condition of a cinder. The density of the gases depends on the force of gravitation; but if we condense them to a fluid state, chemical action takes place. The density, however, would still be influenced by gravitation. If any of the asteroids prove to be more dense than the general laws of density would assign to planets of their respective size, such a condition would indicate that they once were united in a larger body; or, in other words, that these asteroids originally formed a single planet, and that the action of gravity, the suspension of which had caused the separation, had been reapplied to the fragments. Such a catastrophe as we have here supposed might account for the meteoric matter that from time to time reaches the earth.

If we could transport a shaft of granite, a mile in length, from the earth to the sun, its weight, according to the tables, would be increased twenty-eight times. If we were to place it on the body of the sun, it would be increased more than twice that amount. But

as it is impossible to determine how much matter there may be in a state of great rarefaction above the body of the sun, I will assume that the weight of the granite is only doubled by its transfer from the *surface* to the body of the sun. Our granite shaft then becomes equal to a similar one fifty-six miles in length on the surface of the earth.

LXXXVIII.

Spots and Faculæ on the Sun's Surface.

The general brightness of the sun indicates that the surface is near the line of perfect condensation, and that spots are dimmed only at points and places least under the condensing influence of gravitation, as on the equator. These spots may be partially refrigerated islands of matter floating on a fluid sea. Their appearance may be due to the fact that the planets are at a greater distance than usual, or that the limb of the sun on which these spots appear is turned away from the planets. The surface of the sun is brightest when the above conditions are reversed.

The spots may begin to form on the equator of the sun, but become more visible as they are floating off. That they are float-

ing on the body of the sun is indicated by their depressed condition. The outer envelope of the sun is, as it were, a very dense blaze. The illuminated gas overhanging the edge of the spots may, in a measure, illuminate them, producing the penumbra. This view is confirmed by the disappearance of the penumbra at the point of contact when two or more contiguous spots intercept the light.

The faculæ may be caused by the accumulation of floating specks in clusters, through the influence of their mutual attraction, and, by sweeping the surface, they may occasion the increased brightness of the surrounding surface that is apparent just before the formation of a visible spot. When the edge of a spot begins to liquefy, it may begin to grow brighter, and complete liquefaction may cause greatly increased brightness, and produce the more or less elevated protuberances. The surface of a fluid sphere of unequal temperature is always in motion. Some of the particles are carried forward and some backward. This may account for the incongruities in the axial rotation of the different zones of the sun.

As a great increase of density results in a corresponding increase of temperature, and a

degree of intensity is caused by continued condensation that renders matter radiant, the matter of the sun must be luminous. As the temperature of a stratum depends upon its density, the light of the sun must be as permanent as gravitation.

LXXXIX.

The Sun not Deteriorating.

The destruction of the matter of the sun has been discussed by many scientists, and some have made elaborate calculations to show what the annual waste must be, yet matter is indestructible. The constancy in the periodic time of the earth shows that gravitation is constant; this gives the temperature which causes the vibration, a ray, or sunbeam, converted into heat when resisted. If we can count on gravitation as ever acting and never wasting, we can with equal confidence conclude that the sun is not subject to deterioration. Some maintain that the heavenly bodies are cooling off and that the smaller are the colder. That being the case, the darker planets would be growing hot, since they could not radiate heat from their dark surfaces as rapidly as they would be receiving it from the ever-glowing

sun. This process would go on until all the bodies of the solar system were nearly of the same temperature, and then they would cool off together. But when they should all have entered their icy tomb, where should we look for all this heat? Surely not in space, for in that there is no matter, no resistance, and therefore no heat.

XC.

Thickness of Crust of the Earth, Jupiter, and of the Moon.

If we are correct in our conclusion that the body of the sun is a mass of perfectly condensed matter, and that it is kept in this condition by the force of gravity, we are furnished with data that will enable us to determine, approximately at least, the thickness of the earth's crust. We have seen that were a shaft of granite one mile in length to be transferred to the body of the sun, its weight would be increased fifty-six times, or, in other words, it would be equivalent to a similar shaft at the surface of the earth fifty-six miles in length. So, then, if we could descend through a comparatively thin crust, and then through molten matter increasing in density until we had reached the depth of about fifty-six miles, —

making no allowance for loss of weight as we descend, — we should arrive at a perfectly condensed nucleus having the same density and temperature as the sun.

According to the calculations of Professor Proctor, the force of gravity on the surface of Jupiter is about seven times as great as it is on the surface of the earth. Therefore, by the application of the same law that gave us the distance to the perfectly condensed nucleus of the earth, we should reach the corresponding nucleus of Jupiter at the depth of about eight miles.

As the force of gravity at the surface of the moon is about one sixth of what it is at the surface of the earth, making no allowance for loss of weight as we descend below the surface of the moon, we should have to go to the depth of about 336 miles, before we should reach the perfectly condensed nucleus.

If we should find it necessary to limit the solid crust of the earth to the thickness of twenty-eight miles, the application of the uniform law would make the thickness of the solid crust of Jupiter but four miles, one seventh that of the earth, as in the former case. By the same law the moon's crust would be 168 miles in thickness. If the crust

of the earth is 21 miles in thickness, the crust of Jupiter may be 3 miles in thickness, and that of the moon 126 miles. If the crust of the earth should prove to be no more than 14 miles in thickness, that of Jupiter would be about 2 miles, and that of the moon about 84 miles. On the surface of the earth a column of granite about three miles high would have its base crushed by the superincumbent weight. The loss of weight consequent upon the descent below the earth's surface, and the increase of sustaining strength must be taken into account in estimating the thickness of the crust. Making due allowance for these modifying causes, it seems probable that the earth's crust is less than 14 miles in thickness. It may seem that the increase of temperature as we descend into the earth is not sufficiently rapid to warrant the above conclusion, but it should be noted that at the point where granite is crushed the temperature increases rapidly.

The crust of the moon must be thick and rare, with a low conducting power, and low mean surface temperature as compared with the earth.

As the unequal refrigeration and contraction of the interior and exterior portions of

the earth's crust caused the inequalities on its surface, and as rare matter contracts more in the process of refrigeration, the formation and contraction of a rare and thick crust must cause great surface inequalities, such as the appearance of the moon's disk indicates.

XCI.

Location of the Greatest Inequalities.

The crust of the earth is the lightest, as well as the rarest and thickest, at the equator. The greatest surface inequalities are therefore found in the warmer climates, as seen in the altitude of table lands and mountain ranges. The crust being most elevated, rarest, and lightest where it is least affected by gravitation, the greater altitudes, and more than one half of the land, are located in the northern hemisphere. This condition accords with the fact that the inclination of the earth on its axis, and the motion in its orbit, causes the south pole to approach nearer to the sun than does the north pole, subjecting it to more powerful attraction, since the inequality in the influence of the sun on the opposite limbs of the earth increases as the distance between the sun and each of them decreases. It is true

that the variation of the force of gravitation in the two hemispheres is exceedingly slight, but it is also true that the variation in altitudes is very small when compared with the thickness of the crust.

XCII.

Motion of the Line of the Apsides.

As the line of the apsides of the earth makes an entire revolution in about 115,000 years, as calculated by some astronomers, and the uplifts and depressions on the surface are very gradually changing their position, the time may come when the excess of land in the northern hemisphere will be transferred to the southern.

It is known that the sun has a translating motion in space, and that the earth in going round the sun is seven or eight days longer in advancing from the vernal to the autumnal equinox than from the autumnal to the vernal. So the sun moves further in its orbit while passing through the longer of these periods than while passing the shorter, thus causing the line of the apsides to have a very slow rotating motion in space. And by the application of Kepler's first law, we see that

all the heavenly bodies move in elliptical orbits having the attractive body in one of the foci. Hence they do not have a uniform motion in their orbits. This fact together with the motion of the sun must keep their nodes as well as the line of their apsides in motion.

XCIII.

Exterior and Interior Condition of Jupiter.

From statements already made, it is evident that were a shaft of the earth's crust, the height of which should represent the thickness of that crust, to be transported to the planet Jupiter, the weight of the shaft would be about seven times what it was before. Now, had the shaft been originally congealed on that planet, its density and conductivity would have been increased; hence it follows that the melted nucleus of Jupiter must be comparatively large, its crust dense and thin, with a great conducting power that keeps the surface at a high temperature. As the expansive force of heat is most apparent in matter that is least affected by gravitation, the high surface temperature would inevitably convert the surface liquids of Jupiter into a vapory envelope surrounding the planet, thus making it a

comparatively rare body when taken as a whole, that is, as a sphere whose diameter is limited by the outer surface of this envelope. This high surface temperature greatly expands the outer envelope of the sun, and of the other larger planets, as well as that of Jupiter. The same surface expansion may be perceptible in some of the comets as they approach the sun. As dense matter contracts less in congealing, a thin dense crust like that of Jupiter would give but slight inequalities.

XCIV.

Condition of the Planetary Envelopes.

The loss of gravity must cause the outer portion of the envelope of vapor to be very rare, with a correspondingly reduced temperature, as is the case with the upper regions of our own atmosphere. At a low temperature, the reflective power of vapor is greatly increased, and far exceeds that of land and water. That this is the condition of the outer envelopes of some of the larger planets is indicated by their great reflective power, as well as by their variable surfaces.

XCV.

Geological and Meteorological Phenomena upon Jupiter and Saturn.

From the consideration of the crushing force of gravity at the surface of Jupiter, we have seen that the solid crust of this planet may be no more than one mile and a half in thickness. The melted nucleus must be very large when compared with that of the earth; its crust dense and thin, with high conducting power, maintaining the surface at a high temperature. It is probable that all the larger planets are in a similar condition. When fluids are very sensibly elevated by centrifugal force, as is the case on the larger planets, they will form more or less in ridges parallel with the plane of their rotation. This is very easily demonstrated. Light reflected from deep ravines and elevated ridges would cause the surface to have the appearance of variegated belts, and ridges formed of vapor must undergo frequent changes by condensation. The physical disturbing forces on these planets must have great energy. This will account for the violent storms that astronomers have recently observed to be raging on these

bodies. The disturbance is caused in part by the rapid evaporation and condensation, which would give unceasing activity to the leveling forces; and in part, by the rapid motion on their axes, aided by the mass and unequal revolutions of their moons, causing great instability to the planet's axis of rotation; for the more they act in unison the farther they carry the axis of rotation from the position of the geometrical axis, thus keeping up, more or less constantly, a vibration of the axis. Then, too, we are to take into account the unequal masses of the moons of Jupiter accompanied by fluctuations in the tidal waves, causing eight tides in every term of ten hours, continually varying from higher to lower, as the moons act more or less in unison. Changes, and active forces like these, in connection with the nearness of the fluid nucleus to the surface, would necessarily cause volcanic action on a grand and extensive scale. The immense volumes of dark and heated vapor that ascend at times would reduce the reflective power of the vapor overhanging a very large extent of surface. At other times, eruptions would cover vast tracts with molten matter. The heat ascending from such extensive fields of melted lava would, in some degree, disperse

and illuminate the superincumbent vapor. The appearance that we should naturally be led to expect from such action accords very well with the description of the pinky hues recently observed by astronomers. These convulsions may cause the more permanent spots on the disk of Jupiter; those which do not disappear with a reconstruction of the belts. After spots make their first appearance, it has been noticed that their velocity increases, for a while, with each successive rotation. As the ascending vapor leaves the body of the planet, its velocity is much less rapid than that of the outer envelope which it is penetrating, hence the proper motion of the spots is constantly increasing until they acquire the velocity of the outer envelope.

In an article published in "Harper's New Monthly Magazine" for March, 1882, it is stated that "Professor Hall on the 7th of December, 1876 saw a bright spot upon Saturn's equator. It elongated itself from day to day. Such a thing had never before been known upon this planet, and had it not been that Professor Hall was engaged in observations upon the satellites, it would not have been seen then."

I am of the opinion that the bright spot on

the surface of Saturn seen by Professor Hall was the eruption of a volcano of molten matter that advanced from day to day down the side of the volcanic mountain.

XCVI.

Heat Radiated from the Earth does not pass the Limits of the Atmosphere.

Those who have advocated the original fluidity of the earth have maintained that the surface heat has disappeared in space, by radiation, or otherwise, instead of being centralized by conduction. It may be that heat radiates from the surface of the earth, but we have no evidence that it passes the bounds of the atmosphere. Nature seems to have provided an effective barrier against its escape, by saturating the atmosphere with watery vapor, a most active absorbent of radiant heat. If any heat should get beyond the vapor-saturated portion of the atmosphere, it would encounter a rare atmosphere of low temperature, that would expand by the slightest application of heat, and thus the latter would be converted into force before reaching the outer limits of the atmosphere, and whatever conduction there might be would be in

the opposite direction toward the denser matter.

When the surface of the earth was at a fluid temperature, the radiating force was correspondingly intense, but at that primitive period, all the water was held in suspense, forming a vapory envelope that effectually prevented the escape of heat. Neither could heat be conveyed away from the earth by conduction, for in celestial space there is no appreciable matter, as will be shown in the final chapter.

The power emanating from the sun is developed into the quickening influence of heat and light only as it impinges on the atmosphere, or on the body of the planet; the denser the matter on which it impinges the more sensible is the heat. The resistance that condensed nebulous matter originally offered to gravitation caused the solar system to assume a molten condition; and if the force of gravitation should be withdrawn, the matter of which the system is composed would return to its primeval condition.

CHAPTER VI.

PRINCIPLES OF PLANETARY, MOTION AND ETHEREAL RESISTANCE.

XCVII.

Theories of Resistance to Planetary Motion.

Sir Isaac Newton maintained that any ether, however subtle, would act as a retarding medium; and since Newton's day there have been some who were ever ready to attribute any inequality in the motions of the planets to the resistance of an ethereal fluid in celestial space.

Some of the advocates of the vibratory ethereal propagation of light have affirmed that the resistance of this medium to planetary motion has diminished the magnitude of the moon's orbit, and caused an acceleration of the mean motion of this satellite. Others have compared the trajectory of the moon to that of a ball projected from a gun through the atmosphere. In the "Principia," Book III. Prop. 42, Newton says: "Bodies may, indeed, persevere in their orbits by the mere

laws of gravity, yet they could by no means have at first derived the regular position of the orbits themselves from those laws." I believe that this view is generally adopted. Robinson says: "We perceive that the eccentricity of orbits, and mean distances from the sun, depend on the amount and direction of the original impulse or velocity which the planets have in some way obtained, and it is not necessary that the planets should have any definite impulse, either in amount or direction, if the direction is not directly to or from the sun."

In this chapter the attention of the reader will be invited to some remarks upon the laws of planetary motion, and I shall endeavor to establish the improbability that there is any resisting medium in celestial space, and also to show that the simple force of gravitation may have been the primitive cause of planetary motion.

XCVIII.

The Ring Hypothesis of Laplace.

Newton stated that if a ball could be projected in a horizontal direction, from an altitude that would clear every mountain range, and with a velocity sufficient to poise gravita-

tion, and cause the ball to describe an orbit around the earth, it would without any additional impulse continue to revolve in that orbit.

He further maintained that if a body, when projected in free space, is exposed to the action of a central force, varying inversely as the square of the distance, it would revolve in an orbit which would be one of the conic sections.

That Laplace believed in a primitive impulse transverse to the direction of gravity is evident from the following statement quoted from him. "The inertia of matter is most remarkable in the motions of the heavenly bodies, which, during a great many ages, have not suffered any sensible alteration." He favored the theory that the nebulous matter originally existing in space and extending far beyond the orbit of Neptune, after it had been condensed into a rotating spheroid, by its centrifugal force threw off successive rings of matter, as the rotation became accelerated in consequence of gradual condensation. The rings being sustained in their elevated positions by the centrifugal force that uplifted them, and by some cause becoming ruptured, the several portions contracted upon them-

selves, assumed a spherical form, and thus formed planets. According to this theory the original rotating velocity of the rings gave the planets their primitive impulse transverse to the force of gravitation, or, in other words, gave them their centrifugal force.

But if the nebulous matter composing the solar system were condensed into a single rotating spheroid, there would be no foreign matter in the solar system to cause any resistance or axial disturbance. Now if the above theory were correct, the axes of the uplifted rotating rings would be parallel with the axis of the central rotating mass. It would follow, then, that the axes of the planets would be parallel with each other, and also perpendicular to the plane of the ecliptic; but, on the contrary, some of them are greatly inclined. In the case of Venus, the inclination is found to be about 75°.

As the rings uplifted by centrifugal force would have been circular, the orbits of the planets would have been circles instead of ellipses as required by Kepler's first law. If they were originally hurled into space from a single rotating spheroid, their orbits should be parallel in a given plane instead of varying, as they do, more than 34°, and in the case of some of the satellites, more than 78°.

One of the most important statements by which Laplace substantiates his genetic theory is this: "The planets rotate in a direction the same as that in which they go round the sun, and on axes approximately perpendicular to their orbits." Since Laplace wrote this, it has been contradicted, first in relation to Uranus, and more recently in relation to Neptune.

XCIX.

Facts Inconsistent with the Ring Hypothesis.

According to this theory, when the superior rings were thrown off, they must have been of enormous circumference, then there must have been a gradual decrease down to the innermost rings. It seems highly improbable that an uplifted ring should contain the vast amount of matter found in Jupiter and its moons, the next suffice only to form the asteroids, and the one next below contain matter enough to form our earth and its accompanying satellite. The asteroids, unless they are the parts of an exploded planet, must have been formed of independent rings, as they must have been uplifted in circles. Each ring, whether it had been subject to a fracture in one place, or in several places, must have con-

tracted upon itself, and thus have formed a single mass. If the rings of Saturn were uplifted from the body of the planet, they must be uniform in density and distance from the planet, through their entire circumference, for the matter could not have been uplifted unless it were free to move; and centrifugal force would not have thrown up matter in this condition, that was not uniform in density. The stability, in their orbits, of Saturn's rings indicates that the elements do not answer the conditions necessary for the ring hypothesis.

C.

Axial Rotation not Explained by the Ring Hypothesis.

If the orbits of some of the satellites approach so nearly to circles that their orbital motion might be explained by the ring hypothesis, their axial rotation is inconsistent with it, for it is said that the unequal rotating velocity of the inner and outer portions of the rings gave the planets their axial rotation. If so, a similar motion must have been imparted to the satellites, but when we consider their unequal masses, and the axial rotation which must have been imparted, in accordance

with the ring hypothesis, it does not agree with their actual rotation which is caused by their balanced condition. Kepler's first law demonstrates that the matter of which the planets are formed could never have moved in circular orbits; and comets traverse indifferently almost every part of the heavens.

The fallacy of the ring hypothesis is evident when we compare the rotating velocity of the equator of the central mass with the orbital velocity of the nearer satellite. For instance, by the ring hypothesis, when the ring or planet Mercury was thrown off, the sun must have filled the orbit of Mercury, and its equatorial axial velocity must have agreed with the orbital velocity of that planet, which is nearly 110,000 miles per hour. Then, as the sun must have contracted, its rotating velocity must have proportionately increased; and centrifugal force increases with the increase of velocity, and the diminution of the periodic time; but instead of such increased velocity, which would have caused the surface of the sun to fly off into space, the equator of the sun has a velocity of only about 4,500 miles per hour.

CI.

Significance of Recent Discoveries, etc.

The fallacy of the ring hypothesis has received another demonstration by the discoveries that have been made in relation to the moons of the planet Mars. It has been found that the interior satellite travels around the primary a little more than three times while the primary is making a single revolution on its axis. It is impossible that the ring hypothesis should account for this result. In fact all the planets may be moving in their orbits too rapidly to allow the supposition that they were ever attached to the body of the sun.

Newton taught, and the same is presented in our text-books generally, that an impulse in a direction parallel to the horizon would be necessary to project a body from the earth and cause it to "go on revolving through the heavens" in a trajectory like that of the moon's orbit, since the body would have a translating velocity equal to that of the earth. To account for the existing facts on this basis it would be necessary to suppose the direct application of an independent force to each

planet in a direction tangential to the surface of the sun, and to each satellite tangential to the surface of its primary. Not only is such a theory at variance with the known methods of nature, but a simpler one will better account for the facts that require explanation.

As gravitation was an active force in the beginning, solar motion was coëval with it. Planetary matter, which was distributed through space, must have been grouped into independent rotating bodies, as is indicated by the form and orbital velocity of the several planets and satellites.

When we consider the operation of the force of gravitation in connection with the proper motion of the solar system in space, it becomes evident that the matter of which the bodies belonging to this system are composed could never have formed a single coherent mass, as is maintained by the ring hypothesis of Laplace.

CII.

Initial Effects of Gravitation.

When gravitation was first imparted to the matter of the solar system, every particle began to be drawn toward every other particle;

this must result in motion in the direction of the greater force. All particles, therefore, would be set in motion, each falling toward every other, except the more central portions, which would have a more or less balanced position by reason of the opposite attractive force of the surrounding matter. Then, too, all the matter of this system would be moving in obedience to the attractive force of matter beyond its own limits. Its different portions would be moving with unequal translating velocities, in accordance with the law that the force of gravity varies in intensity inversely as the square of the distance.

If the force of gravitation were confined to the matter of the solar system, and this system were at rest in space, the tendency would be for all the particles to fall toward the center, and become consolidated into a single sphere. But as soon as this nebulous mass is subjected to the attractive force of a mass whose center is very remote, all the conditions are changed. The motion of the particles of the solar system is no longer in straight lines toward its own center, for that center is in motion, and the combination of the two is a curvilinear motion of the particles. The tendency would still be for all the matter within

a considerable central segment parallel to the direction of translating motion of the solar system to accumulate in a central mass; and a considerable portion of these particles would strike the growing mass on a line with the motion of translation without any tendency to axial rotation. Others falling more or less on a tangent would thereby generate a comparatively slow axial motion.

Other segments of this nebulous matter outside the central segment already considered, while sharing in the translating motion of the entire system, would be unequally affected by it, some portions moving faster, and some slower, according to the varying force of gravitation. These particles tending toward each other, at the same time that they are drawn toward the center of the system, tend to form new masses moving with velocities varying according to their respective distances and positions from the center, those that are carried forward faster than the center fall before it, while those that move slower than the center fall behind, thus producing the circular or spiral motion as seen in the action of the water, Fig. 2.

Axial rotation would be produced in each of these new masses, or spheres, in the same

way we have shown that it would be produced in the case of the central sun, except that in the latter instance the larger the accumulating mass the more rapid the axial rotation. Then, too, since the masses would conserve both the motion of falling toward the center of the system and the motion of translation which the particles had before they cohered, the path of the mass must be curvilinear toward the central body. Under these circumstances, as the centrifugal force would increase, by reason of the increasing velocity, more rapidly than the force of gravity increases, on account of diminishing distance, hence the planet would depart from the center of motion, the centrifugal force would then be counteracted by the decreasing velocity and the centripetal force, until the latter should gain the supremacy, and then the planet would begin again to approach the center of its motion. The cyclic variation and poising of these two forces compel each new planet to move in an elliptic orbit.

It is evident that every newly-formed planet would itself become a reservoir of attractive power, and thus tend to become a new center for any lesser accumulation of matter that might come within the sphere of its special

control; thus the orbit of a secondary would be determined.

The matter in the segments of the solar system remote from the central segment would naturally consolidate later than the central portions, and in larger masses; and as the elements would be subject to less intensity of the acting forces, they would have less density of structure. All this seems to be in harmony with existing facts as revealed by astronomical observation.

CIII.

Beginning of Orbital Motion.

As the density of matter depends in a great measure on its volume, the unequal mass and density of the accumulating bodies gave unequal density to the opposite portions of the concentrating mass, as is seen in the motion of the satellites, and as may have been the case with the rings of Saturn. Aside from the central mass, the smaller the body the less is the original tendency to an axial rotation; and the nearer the satellites are to the primary, the more unequal is gravitation on the opposite limbs. Thus the denser limbs of the satellites were originally poised toward

the primaries. We have then good reason to conclude that the direct force of gravitation was the genetic impulse in the formation of the solar system, and that in obedience to it homogeneous nebulous matter originally fell from a state of rest, and finally formed in masses, or in rings, as in the system of Saturn.

We see that these masses originally fell by centripetal force, with accelerated velocity, from unequal altitudes toward two common centers, until arrested by centrifugal force, which stayed the downward progress and hurled them off from their centers, causing the orbits of the planets to be more or less elliptical, according to the original position of the matter, and the central body to be located in one of the foci of this elliptical orbit.

CIV.

Composition of Forces.

The centripetal force and the velocity increase as the distance between the bodies is diminished; and centrifugal force increases with the increased velocity of the bodies, or diminished circumference of the orbit. Hence, the nearer the body to the primary, the more

rapid is its orbital velocity, and vice versa, causing the radius-vector to describe equal areas in equal times.

Gravitation, or centripetal force, is continually tending to bring the secondaries to the primaries, and centrifugal force is continually driving them away. The unequal translating velocities of the planets in the different portions of their orbits depend upon the composition of these forces, instead of upon any inertia, or any special impulse that may have been imparted to them at creation. This is indicated by the motion of comets. As they recede from the sun their motion becomes sluggish, and some of them come nearly to a stand-still, their centrifugal force being at this point nearly counteracted by the gravitating force of the sun. In the early genetic day of creation, when the particles first formed in clusters, some of them may have traveled in different directions in space. But as there is a tendency to rotate in a given direction, they were mainly hurled in that direction, as is seen in the motion of the planets, and as has been the case with any retrograde matter or comet that has in any way been entangled with the planets. The union would by adding weight permanently increase the density

and surface temperature, the angle of incidence in impact would determine its effect on the axial rotation.

If the resultant of the translating velocities of these bodies that have been gathered into the controlling sphere of attraction of any planet is less than the velocity of the planet itself, the planet would fall nearer the sun; the centripetal and centrifugal forces would be increased; this would increase the velocity and diminish the periodic times of the planet. This may account for the fact that the planets are generally nearer the sun than the comets are, and that the orbits of the former are more nearly circular.

The remoter matter that did not coalesce and move in obedience to the general tendency probably took shape in some of the comets, and in the moons of Uranus and Neptune.

When the planets first took their form, they may have moved more or less in a transverse direction from the present plane of their orbits, but as they gravitated in a transverse direction from the action of the centripetal and centrifugal forces, the orbits of the planets and satellites approximated to a given plane, and their axes to parallelism.

CV.

Discoveries of Newton and Kepler.

The discovery of the three great laws of planetary motion by Kepler was a sublime discovery, as was also that of the law of gravitation by Newton, to account for the former. Newton conceived that all matter has the power to attract all other matter, and that this force of attraction decreases inversely as the square of the distance from the center of the earth. He established this law of gravitation, by comparing the magnitude of the deviation of the moon from a right line, caused by terrestrial gravitation, with the space through which a body falls, in a given time, at the surface of the earth. He also considered, at great length ("Principia," Book II., sections 6 and 7), the effect that a resisting medium has on a falling body, and in his closing paragraph he says: "The resistance in every fluid is as the motion excited by the projectile in the fluid; and cannot be less in the most subtle ether, in proportion to the density of that ether, than it is in air, water, and quicksilver, in proportion to the densities of those fluids."

CVI.

Question of Interplanetary Resistance Undecided.

It would seem from the number and the delicacy of Newton's experiments that he must have arrived at correct conclusions, but he did not fully decide whether there is any resistance in planetary space. For when bringing forward his theory of "The system of the World," he says ("Principia," p. 513), "The celestial motions are scarcely retarded, by the little or no resistance of the space in which they are performed." It may be impossible to decide this question without extending the researches farther than Newton did, and determining what effect resistance has on a falling body that has an axial rotation; for if the ethereal medium had the effect only to retard the planets, their centrifugal force would be diminished, shortening their orbits, and possibly without affecting their periodic times. In this case, even if there were resistance, we should be unable to detect it.

CVII.

Important Results of Experiment, and their Practical Application.

In the case of the moon, it has been claimed that the resistance accelerates its mean motion. If Newton was correct in his conclusions, there is no subtle ether in the paths of the planets, whatever there may be near the sun, as their motions are not resisted; or if any does exist, it does not retard the motions of the planets. This is made evident by extending the researches of Newton to bodies falling through a resisting medium, these bodies having at the same time an axial rotation.

The results of the following experiment are significant. Having imparted a rotatory motion of a few thousands of revolutions per minute to a solid metallic ball a couple of inches in diameter, and then allowing it to fall through the resisting atmosphere a distance of thirty-five feet, I found that it deviated more than three inches from a true perpendicular.[1]

[1] Some years since this experiment was explained to a United States Army officer of high rank, and although my conclusions were not accepted at the time, they were appropriated and applied in a work on gunnery which the officer issued a few years later.

Although the axial rotation and deviation of the ball from a right line agrees with the axial rotation of the earth and its deviation from a rectilineal path, the deviation of the earth is not caused by any resistance in space, but by gravity; yet, if the translating and rotating velocities of the earth could be maintained in a resisting medium, it might sustain its orbital motion without the aid of any centripetal force. However, the agreement is such that the query naturally arises, whether or not the increased centrifugal force existing in the outer limbs of the planets and the increased tendency of those limbs to move off on a tangent, over and above such tendency in the inferior limbs, has not something to do with their axial rotation.

The curvilinear path of the falling ball shows that if the translating and rotating velocities were perpetuated, it would move in a very small orbit without any centripetal force, simply through the influence of the resistance of the air acting unequally on the opposite equatorial sides of the rotating sphere, at right angles with its motion of translation.

The compression of the air, caused by the rotation of the ball coming in contact with the air which the ball is falling against,

crowds the ball from a vertical line. But if the ball were a projectile, having a rotary motion, as when thrown from a rifle, the motion of the rotation of the air caused by the rotation of the projectile would not coincide with the equatorial plane of the rotating projectile (as in the above case), but would drop back at an acute angle with that plane, and would thus act on the stern of the ball very much as the rudder acts on a ship, causing the ball to turn and drift away from the direction of the projectile force. The more the projectile is elongated, the more perceptible the drifting motion would be. Moreover, while the ball was passing upward from a horizontal line, the air would be crowding on one side, causing the ball for the time being to drift in one direction; but when it was dropping downward from a horizontal line, the air would crowd on the other side, and cause a drifting motion in the opposite direction.

Independent of the effect which the atmosphere has on the rifle projectile, it is well known that the tendency of the rotation is to hold the equator of the ball in a given plane and to keep the axis of rotation constantly parallel to the position it had previously occupied, as is illustrated by the movement of the earth in its orbit.

This tendency was indicated by the behavior of the projectiles used in the earlier bombardments of Charleston, in our late civil war.

CVIII.

The Distances and Periodic Times of Planets and Comets Indicate the Absence of a Resisting Medium.

According to Newton's theory, if there is any subtle ether, the falling ball must be resisted, and the deviation of the rotating falling ball demonstrates that if the motion of the planets were resisted, their masses, variation in axial rotation, and the translating velocities in their orbits being so unequal, the magnitude of their orbits, and their periodic times, must be unequally diminished.

Their periodic times would not then be assignable by Kepler's third law, or by Newton's law of gravitation. The distance between the earth and the sun, and the periodic time of the earth, would be diminished, and the distance between the earth and the moon would be increased, as would be the periodic time of the moon. These results would be caused by the unequal dimensions and unequal axial rotation of these bodies. On ac-

count of the decrease in the periodic times of Encke's and Fay's comets, Encke assumed that planetary space is pervaded by an extremely rare medium. But, as it is demonstrated that the motion of the planets is not resisted, and the orbits of these comets are interplanetary, the decrease in their periodic times cannot be accounted for by that theory.

Again, the unequal variation of their periodic times conflicts with the same theory. To account for this, it has been conjectured "that the resistance arises from collision with innumerable small bodies revolving about the sun." That these bodies exist in abundance is evident; but the effect they may have on the periodic times of the comets can hardly be determined by experiment.

There is another proof that no resisting medium pervades the space in which the earth's orbit lies that, so far as I am aware, has not been noticed, viz., The existence of such a resisting medium would inevitably produce a decided effect upon the earth's atmosphere, causing it to be very unequally distributed over the earth's surface — the greater portion following behind, so that were it illuminated and visible to an outside observer, it would present an appearance somewhat like the tail of a comet.

CIX.

Author's Conclusions Harmonize with Scriptural Representations.

As the density of matter depends upon the conditions determined by the force of gravitation, matter must have existed, prior to its condensation, in a gaseous or nebulous form. I believe that this view of the primitive condition of matter harmonizes with the account of creation given by Moses in the Book of Genesis. From that we learn that the heavens and the earth had a material beginning. As in the first chapter of St. John we are told of the spiritual beginning, or the entrance of the Spirit into the world. Moses tells us that the matter of which the earth is composed "was without form," indicating that it was a very rare fluid, to us "a void," and that darkness was upon the deep, or abyss of celestial space, until the "Spirit of God moved (by the agency of gravitation) upon the face of the waters," or fluids, to condense them. "And there was light;" when the surface of the earth became refrigerated and dark, "God divided the light from the darkness," but the length of time intervening is not specified. "And God called the light day, and the dark-

ness he called night. And the evening and the morning were the first day," or period. It is well to note the words of St. Peter: "But, beloved, be not ignorant of this one thing, that one day is with the Lord as a thousand years, and a thousand years as one day." It was necessary that the fluid, or "waters which were under the firmament," should be "divided from the waters which were above the firmament" in the formation of the solar system from nebulous matter. After the waters were thus divided, and the planets formed, "God called the firmament," or celestial space, "heaven."

The primitive condensation would cause a high temperature. The waters were held in suspense until the surface refrigeration formed mountains and valleys as we are told: "There went up a mist from the earth and watered the whole face of the ground." When the surface temperature became sufficiently reduced to allow the suspended fluids to be condensed, "the waters under the heavens were gathered together into one place," the depressed portions of the earth, "and the dry land appeared." When the overhanging mist became condensed, "the lights were set," or became visible, "in the firmament of the

heavens, to give light upon the earth." The first verse of the first chapter of Genesis, in an introductory way, speaks of the creation of the heavens and the earth. The second, third, fourth, and fifth verses speak more particularly of the creation of the earth. The sixth, seventh, and eighth relate to the creation of the solar system. The ninth to the thirteenth inclusive speak still further of the creation of the earth. The fourteenth to the eighteenth inclusive tell us of the earth and the appearance of the solar system, after the surrounding mist, or waters, had been gathered together into one place. The last cited verses determine the division of time into seasons and days and years as we have them now, except that the length of the day has decreased by a very small fraction, since the fourth day, or period, of creation, by the refrigeration, or very slight contraction of the earth which took place in the early period.

CX.

Space Originally Pervaded by Homogeneous Nebulous Matter.

We are therefore led by revelation, as well as by science, to believe that the matter of

which the earth and planets were formed originally pervaded space in a homogeneous nebulous form. If the density of the solar system were estimated in accordance with this theory, a cubic mile of such matter, it is said, would weigh less than a cubic inch of our atmosphere, and space thus occupied might well be called a "void."

When the matter of the solar system was in a nebulous form, and the force which caused particle to attract particle was imparted to it, the planetary system, following nature's laws, took its form fitted for life.

CXI.

The Consummation.

If the force of gravitation should be removed from the solar system, many prophecies in Holy Writ would be fulfilled. The sun would "become black," owing to expansion; but the moon and the earth would be melted and "become as blood;" "and the stars" or planets, by expansion, "would fall unto the earth, and the heavens depart as a scroll when it is rolled together." Rev. 6: 12–14. Isaiah 34: 4.

Independent of translating forces, the ex-

pansion of matter in so many conflicting directions might tend to restore comparative rest.

Again, if we look out into the starry heavens, the probability that the earth is to be burned up is confirmed. Astronomers have computed that more than fifteen hundred fixed stars have disappeared within the last three centuries. Some of these stars may have become dark and invisible by surface refrigeration, as is the case with the earth. Others have given the most indisputable evidence of having been consumed. Their light has broken forth with such splendor that they could be seen by the naked eye, at noonday, and at night through a canopy of clouds. After the conflagration had been visible for a few months, the stars disappeared.

May the Creator of the universe grant that we may be prepared for that hour, when our works shall be tried by fire.